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The Effects of Process Design on Reduced Water Use and Waste in Dairy Processing

Dr. Roy E. Carawan
Dr. W. James Harper

Department of Food Science and Nutrition
The Ohio State University
Columbus, Ohio 43210

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By
Roy E. Carawan, Ph.D.
North Carolina State University
and
W. James Harper, Ph.D.
The Ohio State University

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THE OHIO STATE UNIVERSITY

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PROJECT STAFF

Principal Investigators
Dr. W. James Harper
Dr. Elbert E. Whitlatch, Jr.

Research Assistant
Dr. Roy E. Carawan

Project Consultants
Dr. John L. Blaisdell
Mr. Dale Seiberling
Dr. Francis E. Walker

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NOTE

Throughout this report BOD means BOD_5

EXECUTIVE SUMMARY

THE EFFECT OF PROCESS DESIGN ON REDUCED WATER USE AND WASTE IN DAIRY PROCESSING

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The Ohio State University, 1980

Procedures are presented for evaluating management and process modifications in a case study medium-sized multiproduct dairy plant with wastewater discharge to a municipal sewer system. This investigation includes the following: (1) a description of the Case Study Plant; (2) an identification of the production processes; (3) estimation of water use, wastewater discharge, product loss, and waste contribution including both biochemical oxygen demand (BOD) and fats, oils and greases (FOG) for each process; (4) specification of process alternatives for water and waste reduction; (5) identification of the benefits and costs associated with each process alternative; (6) formulation of linear programming solutions of the linear economic model to evaluate the effects of increasing water and surcharge costs, effluent concentration restrictions and the introduction of selected process alternatives in the Case Study Plant.

The basis used for evaluating the 21 water and waste reduction changes was a Benchmark established from modified literature values. The reductions for the process alternatives were estimated after an assumed initial reduction for Management Action in which water use and waste loads were reduced by 50 percent of the Benchmark. All the changes were shown to be cost effective for the Case Study Dairy. The incorporation of the Management Action program and all applicable process alternatives was shown to reduce the water use in the Case Study Plant 72.4 million gallons per year. The waste reduction was found to be 1.57 million pounds of BOD. The annual net savings were estimated to total some $921,000. Investment was $333,000 and annual increased costs were $170,808.

A linear economic analysis model was developed for evaluating the effects of water use costs, surcharge (BOD) costs, effluent restrictions and to choose process alternatives for least cost plant operation. The Case Study Plant is presented in a linear programming format comprized of approximately 150 activities and 150 rows. The model was run using International Business Machines Corporation (IBM 370/135) computer using the Mathematical Programming System (MPS/360A-CO-14X) version 2. Included is a model description and a data matrix. Each solution of a model: (1) identifies an optimal plant configuration consisting of production processes (2) gives the least cost of operation (3) indicates the marginal cost of any restriction; and (4) gives the activity of products, dairy products, water use, wastes (BOD and FOG), and wastewater for that particular combination of inputs.

Solutions of the linear analysis model confirmed its usefulness at predicting the inclusion of water and waste related process alternatives in the product process sequences of the Case Study Plant. Perhaps more important was the extreme sensitivity shown by the Case Study Plant to BOD and FOG effluent restrictions. A BOD restriction of 250 mg/l provided an infeasible solution even when over 90% of the required product demand could be bought. The combination of a BOD restriction of 2000 mg/l and a FOG restriction of 250 mg/l limited production in the Case Study Plant to a combination of 6% of the desired fluid milk, 65% of the desired cottage cheese and eliminated the processing of ice cream.

Without process alternatives, and an effluent BOD, restriction of 2000 mg/l, the Case Study Dairy could produce no ice cream, no cottage cheese and only 25% of the desired fluid milk. With all available process alternatives, and an effluent BOD restriction of 2000 mg/l, the Case Study Dairy could process 100% of the ice cream, 100% of the fluid milk and 23% of the desired cottage cheese.

TABLE OF CONTENTS

INTRODUCTION

The 1960's saw a great number of Americans concerned about the protection of their environment. The interest in the environmental area concerning protection of the waters culminated in 1972 with the passage of Public Law 92-500, which went so far as to make it a national goal to eliminate pollutant discharge by 1985.

Two areas of regulations have been implemented by the United Stated Environmental Protection Agency (EPA) under the authority of Public Law 92-500 and which subsequent amendments significantly impact the dairy industry. First, the requirements for effluent standards and limitations place stringent requirements for treatment of dairy plant wastewater discharge to the waters of the United States. Second, the requirements that municipalities receiving federal monies prohibit toxic and unusual wastewater discharges and achieve an equitable recovery of cost from all industrial dischargers will place an economic burden on the dairy industry.

Municipalities continue to pass sewer use ordinances which: (a) severely restrict or prohibit what can be discharged into the municipal sewer system, (b) include surcharges and/or cost recovery provision and (c) may require pretreatment. These ordinances have and will continue to effect the United States dairy industry since more than 90 percent of the dairy plants producing ice cream and fluid milk products discharge their wastewaters to municipalities.

The waste load in the dairy industry is largely a result of milk products which are intentionally or inadvertently lost to the sewer system. Improved operation and management practices may effectively reduce much of the water use and waste load that is generated in dairy processing.

The reduction of water and waste in a dairy processing plant requires the application of the best technology to achieve reduced product loss, reduced water usage, and reduced ingredient loss. Moreover, water and sewer costs are now important. Surcharges (user charges) require payment for the discharge of waste load in terms of biochemical oxygen demand (BOD), suspended solids, pH, and/or hydraulic loads. Dairy plants now have monthly water and sewer bills that may exceed $10,000 with a surcharge. Increasing wate and sewer rates are common.

A proven way to reduce water use, wastewater discharge and waste loads discharged is to operate the plant more efficiently. Another is to institute process changes which have been demonstrated to reduce water use and wastes. There are many alternative process schemes known but not generally practiced in the dairy industry. Many of these alternative processes reduce product loss and wastes in dairy processing. A number also reduce water use and wastewater discharge.

The primary objective of this investigation was to develop an analysis of a case study multiproduct dairy processing plant producing fluid milk products, cottage cheese and ice cream which could relate to management least cost solutions of water and waste related costs. Water and waste related costs are those costs that are associated either with water utilization or waste disposal. The authors have identified the following costs as water and waste related for this investigation: (1) water cost (2) sewer cost (3) surcharge costs for dairy wastewater concentrations greater than those found in domestic sewage (4) the costs associated with processing products that are lost to the drain and (5) the initial cost of raw products.

A second goal was to develop the necessary inputs needed to develop a linear economic model of the Case Study Plant. Linear programming was thought to be an excellent tool to efficiently study the multitude of water and waste related alternatives known to be useful in dairy processing.

The final objective was to develop an integrated linear programming model capable of evaluating the significance of potential process modifications to reduce water and waste loads.

The influence on production costs of external restraints such as maximum BOD restrictions and hexane solubles (fats, oil and greases - FOG) restrictions were also selected for analysis. The range of BOD and FOG restrictions considered were found in typical sewer use ordinances. The Case Study Plant was developed with an alternative of buying the major products produced rather than processing them. This option allowed the consideration of effluent restrictions. As the processing of products produced wastes that exceeded the effluent limitation, the buy products options allowed the Case Study Plant to meet the assumed sales demands when external restraints restricted processing.

LITERATURE REVIEW

Introduction

Wastewater from a dairy processing facility consists largely of milk products diluted with water. However, domestic wastes, lubricants, detergents, sanitizers, boiler treatment compounds and oils often find their way into the wastewater stream. Harper *et al*. (1971) found that 90% of the five day biochemical oxygen demand (BOD) in dairy wastewaters could be attributed to milk products. There appears to be a consensus among those who have studied waste control in the United States dairy industry that management can effect a 50% reduction in water and waste loads (Harper *et al*., 1971; Zall and Jordan, 1969 and 1973 and Carawan, *et al*., 1972 and EPA, 1974). With process and engineering changes, the Development Document (EPA, 1974) predicted the minimum achievable wastewater discharge would be 100 gallons wastewater and 0.5 pounds of BOD per 1000 pounds ME processed. This would be a BOD concentration in the wastewater of 600 mg/l.

This review is not intended to be a complete listing of all known references about water and waste management and treatment in dairy processing. Anyone desiring such a review should see Harper *et al*. (1971). Other key references in water and waste management of dairy wastes include Carawan (1977), Development Planning and Research Associates (DPRA, 1976), EPA (1974), EPA (1973), Jones (1974), Federal Water Pollution Control Administration (FWPCA, 1967), Harper (1972, 1974), Carawan *et al*. (1973), Milk Industry Foundation (MIF, 1967) and Public Health

Service (PHS, 1959).

Dairy Processing Wastewater Characteristics

This review will center on those aspects that relate directly to the objectives of this investigation.

Sources and Nature of Wastewater

Pollutants in the wastewater from dairy processing consist primarily of lost milk products (Harper, 1974). The authors of the Development Document (EPA, 1974) outlined the sources of wastes as presented in Table 1. Possibly 94% of the BOD load from a dairy plant are lost to the sewer by the first five items. Non-dairy ingredients also contribute to the BOD load including sugar, fruit, nuts, cleaners, sanitizers, lubricants and domestic sewage.

Wastewater is discharged from many of the operations around a dairy plant (Carawan *et al*., 1972). Examples of processing equipment given included homogenizers, fillers and case washers.

Cooling water for refrigerant condensers and heat exchangers is often discharged to the sewer with little or no contamination or pollutants (EPA, 1974). Roof drains were also mentioned (EPA, 1974) as entering the sewer system although model sewer use ordinances restrict this when storm sewers are available (WPCF, 1974). Truck washing facilities contribute wastewater (Carawan *et al*., 1972).

Dairy Wastewater Parameters

The authors of the Development Document (EPA, 1974) concluded that dairy wastewater parameters of significance

Table 1. Sources of Waste in Dairy Plants.[a]

Number	Description of Source
1.	The washing and cleaning out of product remaining in tank trucks, cans, piping, tanks, and other equipment performed routinely after every processing cycle.
2.	Spillage produced by leaks, overflow, freezing-on, boiling-over, equipment malfunction, or careless handling.
3.	Processing losses, including: (a) Sludge discharges from CIP clarifiers; (b) Product wasted during HTST pasteurizer start-up, shut-down, and product change-over; (c) Evaporator entrainment; (d) Discharges from bottle and case washers; (e) Splashing and container breakage in automatic packaging equipment, and; (f) Product change-over in filling machines.
4.	Wastage of spoiled products, returned products, or by-products such as whey.
5.	Detergents and other compounds used in the washing and sanitizing solutions that are discharged as waste.
6.	Entrainment of lubricants from conveyors, stackers and other equipment in the wastewater from cleaning operations.
7.	Routine operation of toilets, washrooms, and restaurant facilities at the plant.
8.	Waste constituents that may be contained in the raw water which ultimately goes to waste.

[a]Development Document (EPA, 1974)

include BOD, COD, suspended solids, pH, temperature, phosphorus (phosphates), nitrogen and chlorides. These authors feel that fats, oils and greases (FOG) should also be included as a significant dairy wastewater parameter. The Development Document, Harper et al. (1971) and Carawan (1977), go into great depth in discussing the source and concentration of these parameters. The review is focused on the four following factors: wastewater discharge, biochemical oxygen demand (BOD), and fats, oils and greases (FOG).

BOD Biochemical oxygen demand (BOD) is a measure of the oxygen consuming capabilities of the organic matter during normal decomposition as one would expect in a stream with adequate dissolved oxygen (DO). The standard BOD test is run for 5 days at 20C (BOD). BOD_{20} refers to a BOD test run for 20 days at 20C. BOD for dairy wastewaters is expressed either as concentration (mg/l or ppm) or as the BOD coefficient relating BOD load to some measure of production.

The BOD concentration of dairy wastewaters range from 750 mg/l to 4,200 mg/l (Harper, 1974). Total daily loads from dairy plants range from 18 pounds to 6699 pounds (EPA, 1974).

Harper et al. (1971) presented a formula for estimating the BOD of dairy products. The formula was presented with BOD found by assuming that each pound of milk fat, lactose (or added sugar) and milk protein equals to 0.89, 0.65 and 1.03 lbs BOD respectively.

The Development Document (EPA, 1974) reviewed the BOD loads from dairy processing plants. Selected data is presented in

Table 2 for both results abstracted from the literature and an industrial survey. Mean waste loads for the fluid milk, cottage cheese, ice cream or combinations of all three ranged from 3.21 to 14.64 lb (pounds) BOD/1000 lb of milk equivalent received. The range of loads was presented as 0.14 to 42.0 lb BOD/1000 lb milk equivalent received. The lowest value was for a fluid milk plant while the highest was for a cottage cheese plant. The wide range in values even for one type of plant confirm the results of the Harper et al. (1971) survey.

The combination fluid milk, cottage cheese and ice cream had a literature mean of 6.79 and a plant identified source of 6.24 lb BOD/1000 lb of milk equivalent.

FOG Fats, oil and greases (FOG) are important to dairies primarily because many municipalities have sewer use ordinances which restrict FOG to 100 mg/l (WPCF, 1975). Hansen et al. (1975) noted that over two-thirds of the North Carolina dairy plants surveyed had FOG levels greater than 300 mg/l. Carawan et al. (1972) found that FOG was 32% of the BOD for a multiproduct dairy. FOG was observed in the effluent from the frozen products freezing area at concentration ranging to 7500 mg/l. Milk fat, which is biodegradable, is the main fat found in dairy wastewaters (EPA, 1974).

Water Use and Wastewater Discharge. The dairy industry reportedly takes in more water than it does milk (Renwick, 1975). Each gallon of milk processed was said to require about 1.5 to 2.0 gal (gallons) of water (Renwick, 1975). Hall and Trout (1968) reported dairy water use at 0.75 to 1 gal/lb of milk

Table 2. Summary of Literature Reported and Identified Plant BOD_5 Data.[a]

Type Plant	Literature[b] Number of Plants	Literature[b] BOD_5 Load per ME[d] Received Range	Literature[b] BOD_5 Load per ME[d] Received Mean	Identified Sources[c] Number of Plants	Identified Sources[c] BOD_5 Load per ME[d] Received Range	Identified Sources[c] BOD_5 Load per ME[d] Received Mean
		(lb/1000 lb)			(lb/1000 lb)	
Fluid Products	16	0.14-17.06	3.60	6	0.30-7.16	3.21
Cottage Cheese	5	1.30-42.00	14.64	-	-	-
Ice Cream	7	1.90-21.04	5.54	10	0.68-19.60	6.75
Fluid-Cottage-Ice Cream	10	0.90-12.90	6.79	1	-	6.24

[a]Development Document (EPA, 1974)

[b]Literature = Values obtained from literature review

[c]Identified Sources = Data obtained from operating plants which could be identified by name and location

[d]ME = Milk equivalent

processed.

Carawan <u>et al</u>. (1972) made an extensive study of the water requirements of a multiproduct-fluid milk, cottage cheese and ice cream dairy plant. The data has been modified by Jones (1976) to include more results and to correct minor errors. Plant water use is shown in Table 3. The total use was 448.4 gal water/1000 lb of products processed with specific use for processing of 434 gal/1000 lb of product.

The water used for the various products is exhibited in Table 4. The water use for fluid products was 205 gal/1000 lb. Water use for cottage cheese and ice cream production was approximately 10 fold the water use per unit product for fluid products.

Wastewater coefficients are shown in Table 5 for fluid product, cottage cheese, ice cream and combined plants producing all three products (EPA, 1974). As only 16 plants were included in the fluid products survey, it is questionable if this data is representative of the more than 2000 United States fluid milk processing plants. The other type plants had even fewer plant numbers included in the survey. The ranges for the coefficients suggest that considerable caution should be employed in using the data.

Harper, <u>et al</u>. (1971), also did an extensive survey of a number of plants. Partial results of the survey are presented in Table 6. Both the number of plants surveyed and the uniformity of information collected and analyzed suggest somewhat more validity for these results than for others reviewed previously.

Table 3. Plant Water Use Per Unit Product.[a]

Area	Average Water Use/Product[b] (gal/1000 lb)
Processing Plant	434.
Offices	2.4
Refrigeration Shop	1.2
Garage	10.8
Total Use	448.4

[a]Jones, 1976

[b]Total products products

Table 4. Average Water Use Per Unit Product.[a]

Product	Average Water Use/Product (gal/1000 lb)
Fluid Products	205
By-Products (Cottage Cheese)	1982
Frozen Products	2146
Total Products	434

[a]Jones, 1976

Table 5. Summary of Literature and Identified Plant Source Wastewater Volume.[a]

Type Plant	Literature[b]			Identified[c]		
	Number of Plants	Wastewater per ME[d] Received		Number of Plants	Wastewater per ME[d] Received	
		Range	Mean		Range	Mean
		(gal/1000 lb)			(gal/1000 lb)	
Fluid Products	16	13-1,090	369	11	52-1,020	464
Cottage Cheese	5	100-1,504	928	-	-	-
Ice Cream	7	93-667	357	12	63-844	486
Fluid-Cottage-Ice Cream	12	96-1,381	425	1	-	278

[a]Development Document (EPA, 1974)

[b]Literature = Values obtained from literature review

[c]Identified = Data obtained from operating plants which could be identified by name and location

[d]ME = Milk equivalent

Table 6. Wastewater Coefficient for Commercial Plant Survey.[a]

Manufactured	Number of Plants	Wastewater Coefficient (Wastewater/Milk)		
		Range[b] (lb/lb)	Average[b] (lb/lb)	Average[b] (gal/1000lbs)[c]
Milk (FM)	6	0.1-5.4	3.25	389
Ice Cream (IC)	6	0.8-5.6	2.80	336
Cottage Cheese(CC)	3	0.8-12.4	6.00	719
FM,IC,CC	9	1.4-3.9	2.52	302

[a]Harper *et al*. (1971)

[b]Based on milk received

[c]Calculated $\frac{\text{lb wastewater}}{\text{lb milk}} \times 1000 \text{ lbs milk} \times \frac{\text{gal water}}{8.34 \text{ lbs water}}$

The wastewater coefficient for the nine combination fluid milk, cottage cheese and ice cream was 2.52 lb/lb of milk received (302 gal/1000 lb).

Control of Dairy Wastes

Introduction

There have been a number of ideas expressed about the need for wastes prevention in the dairy industry (McKee, 1965; MIF, 1967; Zall and Jordan, 1969; Harper *et al.*, 1971; Carawan *et al.*, 1972; EPA, 1974, DPRA, 1975 and Carawan, 1977). The most important of the reasons given by MIF, 1967a were the following: 1) Direct dollar savings and 2) Compliance with regulations.

Dollar savings have been reported to result from water use reductions (Zall, 1968 and Carawan *et al.*, 1972), energy reductions (Zall, 1968, reduced losses of product and raw materials (MIF, 1967; Zall, 1968; Harper *et al.*, 1971; Carawan *et al.*, 1972; EPA, 1974 and DPRA, 1975) and by-products usage (MIF, 1967a; Zall, 1968; Harper *et al.*, 1971; Carawan *et al.*, 1972; Zall and Goldstein, 1973; Schingoethe, 1976; Jelen and Buchheim, 1976 and Watson, 1977). Compliance with regulations would include discharge to receiving streams (EPA, 1974 and DPRA, 1976) and discharge to municipalities (Harper *et al.*, 1971; Carawan *et al.*, 1972; EPA, 1974 and DPRA, 1975).

There are two separate but interrelated areas of the problem of controlling water use and waste in dairy plants. First, there is the water wastage problem with its accompanying hydraulic load problem. Second, there is the milk solids problem which creates the waste load problem whether it be BOD, fats or suspended solids.

The most important rule given for waste saving and waste disposal is that milk solids should be completely utilized so that no product containing milk solids is flushed to the drain (MIF, 1967; Arbuckle, 1970). Cotten (1976) indicated that 1 to 4% of the milk-input to dairies is wasted without including whey. Over 96% of the BOD load from fluid milk processing plants has been estimated to come from milk solids (DPRA, 1975). All of the authors who have studied dairy wastes conclude that lost milk components are the problem in dairy wastewaters. MIF (1967) urged dairy plants to make it a cardinal rule that no spoiled milk or milk product be dumped into the sewer system.

Harper _et al_. (1971) refuted the prevalent view in the dairy industry that the elimination of whey from dairy plant wastewaters would essentially solve the problem of fluid pollution from the dairy industry. Site visitations and examination of waste coefficients for dairy plants indicated that although whey was a large part of the problem, BOD coeffients still ranged from 0.7 to 9.6 lb/1000 lb milk received in plants handling cottage cheese when whey was excluded.

In-Plant Control Measure

The control of dairy wastes requires many in-plant measures which combine to effectively reduce wastes. A number of these were listed by McKee (1965):

(1) See that the entire program has the active support of management.

(2) Install modern equipment and piping in order to reduce wastes.

(3) Impress the people working in the plant with the importance of reducing wastes.

(4) Secure the proper separation of wastes into process wastes, sanitary sewage and clean water.

(5) Provide for recovery of by-products.

(6) Select and install the waste disposal system best suited to your plant.

(7) Follow through with good operation and maintenance in both the dairy plant and the waste treatment plant.

Plant Management Improvement. Management is one key to the control of water resources and waste within any given dairy plant (EPA, 1974). The authors observed that a clear understanding of the relative role of engineering and management supervision in plant losses is needed by management.

The best and most modern engineering design and equipment cannot along provide for the control of water and waste within a dairy plant (EPA, 1974). A new (six-month old), high-capacity, highly automated multi-product dairy plant, incorporating many advance waste reduction systems, was found to have a BOD level in its wastewater of more than 10 kg/kkg (10 lb/1000 lb) of milk equivalent processed. This unexpected and excessive waste could be related directly to lack of management control of the situtation and poor operating practices.

Harper (1974) observed that management must do their part to have an effective water and waste control program in dairy processing. Mangement's role as presented by Harper included:

(1) Understanding water and waste control in dairy processing including the need for such a program, the economic benefits that can be accrued and being

cognizant of all interrelated factors,

(2) Developing job descriptions for all plant personnel,

(3) Providing an environment that permits supervisors to supervise waste management and

(4) Utilizing a continuing education program.

Harper et al. (1971) made visitations to evaluate management practices at 20 dairy plants for which waste data was available. After their visits they developed a number of criteria for evaluating a dairy plant's water and wastewater management practices as shown in Table 7. Although their criteria were described as subjective in nature and not lending themselves to quantitation, they concluded that the listing lends itself to describing the over-all quality of management practices with respect to waste control. They recognized and demonstrated the influence of management practices affecting waste coefficients, both volume and BOD coefficients. The minimum levels thought attainable with current technology were 100 gal wastewater/1000 lb milk received and 0.5 lb BOD/1000 lb milk received.

Employee Education Program. Carawan et al. (1972) observed the need for a program of employee education in water and waste related areas for dairy processing employees. A program was presented and has been modified after actual plant use (Carawan and Jones, 1977).

The key to a successful water and waste management program was postulated as a water-waste supervisor with responsibility for plant water use and waste (Carawan and Jones, 1977). Their program places emphasis on management knowledge and action. All

Table 7. Criteria for Evaluating Dairy Plant Management Practices.[a]

Number	Criteria
1.	Housekeeping practices.
2.	Water control practices; frequency with which hoses and other sources of water were left running when not in actual use.
3.	Degree of supervision of operations contributing to either volume or BOD coefficients.
4.	Extent of spillage, pipe-line leaks, valve leaks and pump-seal leaks.
5.	Extent of carton breakage and product damage in casing, stacking and cooler operations.
6.	Practices utilized in handling whey.
7.	Practices utilized in handling spilled curd particles during cottage cheese transfer and/or filling operations.
8.	Utilization of practices to reduce the amount of wash water from cottage cheese or butter operations.
9.	Extent to which the plant is utilizing procedures to segregate and recover milk solids in the form of rinses and/or products from pasteurization start-up and product change-over.
10.	The procedures utilized in handling returned products.
11.	Evaluation of the management attitude toward waste control.

[a]Harper *et al.*, 1971

plant employees are scheduled for four hours of instruction in water and waste management terminology and techniques.

Segregation of Dairy Wastes. Harper et al. (1971) cautioned that when planning new dairy plants or remodeling existing facilities, consideration should be given to the segregation of those sewers expected to receive high BOD wastewaters. These wastewaters could be returned to a tank for waste load equalization or subjected to pretreatment. These wastes included lubricants, milk from filling areas, solid particles from cottage cheese operations, high-temperature short-time (HTST) discharge and cleaning-in-place (CIP) discharge.

Scheduling. Scheduling is one of the best waste controls in the dairy processing plant (Zall and Jordan, 1973). An example was given of running chocolate milk between two white products thereby requiring two water rinses between the products with two flushings of product-water to the sewer. Unnecessary shutdowns or other interruptions were said to almost always produce product losses to the sewer.

By-Product and Waste Product Utilization. Harper et al. (1971) pointed out that because of the national attention and visibility of whey as a waste product, the dairy industry was aware of the significance of using whey as a food or feed product to minimize pollution and to gain a profit from such operations. However, they indicated that the dairy industry was less aware of the potential in respect to the utilization of product rinses; such as diluted milk solutions resulting from start-up, change over and shut-down of pasteurizers on water and the recycling or utilization of returned product.

The complete removal of whey from wastewaters is a continuing problem in the United States. Harper _et al._ (1971) estimated that about 20% of all the milk processed ends up as whey of one type or another. Also, there is a limited market for whey solids as well as technological problems in developing products from whey. Acid whey, because of the presence of 0.5 to 0.7% lactic acid, provides problems in respect to drying the material and also in respect to its utilization in food (Harper _et al._, 1971). Groves (1972) concluded that many industry leaders still feel that whey is a disposal product or hog feed rather than a food. Groves noted that, for Wisconsin whey (other than cottage cheese), use had gone from less than 30% to 91% in ten years. Jonas _et al._ (1976) estimated that for the entire United States 70 to 74% of the sweet whey is utilized while only 20% of the acid whey is utilized. Development Sciences, Inc. (1975) concluded that small to medium size cheese plants need assistance to efficiently utilize energy to recover whey components for food instead of treating the whey as a wastewater.

Foam spray-drying, foam mat drying, reverse osmosis, gel filtration for protein recovery, utilization or the growth of yeast protein, fermentation and animal feed use are all methods which have potential for the conversion of whey into more usable forms (Harper _et al._, 1971).

Harper _et al._ (1971) indicated the potential exists for collection of all the milk solids present in rinse waters from tank truck storge tanks, lines and equipment, for saving the milk solids diverted to drain in the start-up, changeover, and shut-down of HTST pasteurizers and of milk solids in returned products. They estimated that up to one pound of BOD per thousand pounds of milk processed could be eliminated from wastewater through the collection and utilization of these solids. These diluted milk solids are considered to be adulterated products by many health officials and changes in laws and regulations will have to be made to permit their utilization in foods.

Harper _et al_. (1971) observed that methods of segregation and utilization of these dilute materials are needed. Two possibilities were mentioned with present laws and technology. First, a possibility exists at the present time of using them in ice cream mix or any other product where solids must be added to the material. Second, the possibility also exists of utilizing reverse osmosis to concentrate the materials.

Harper _et al_. (1971) related that dairy automation systems could be used to help recover rinses from tankers, tanks and lines. They reported that a 6000 gal raw milk tanker normally was rinsed with 250 gal of water and this rinse contained 9.10 lb BOD. An initial 30 gal burst-rinse could recover 7.5 lb BOD. The rinse contained 1.5% butterfat for high solids products or rinses from tank trucks which had set over 1 hour before unloading.

Water Use Reduction. The reduction of water use will simultaneously reduce wastewater discharge. Farrall (1976) has reported a number of techniques to reduce water use. First, controlling water use at hose stations with shut-off nozzles. Second, solenoid valve installation for equipment which is operated intermittently such as can washers, condensers and other equipment. Third, water regulating valves should be used for refrigeration systems where the volume of water needed can be influenced by the system head pressure. Last, he urged the use of evaporative condensers for refrigeration systems to achieve as much as 95% water reduction when an evaporative condenser replaced a shell-and-tube condenser.

A number of water conservation measures were suggested by MIF (1967d) and they are presented in Table 8.

Proper Design and Utilization. Harper *et al* (1971) observed that as plants incorporated cleaning-in-place (CIP) and process automation capabilities, proper design of plants and processes can afford material reductions in waste loads. The theoretical effect of advance technology on reduction of waste load was illustrated in Waste Profile No. 9. (FWPCA, 1967). Such reduction, as that predicted for fluid milk plants, has not occurred in real practice within the industry at the present time (EPA, 1974). Indeed, in some cases, utilization of automation and mechanism were reported to have increased the BOD coefficients. Harper *et al*. (1971) postulated that this increased waste was because large complex plants are more difficult to manage.

Harper *et al*. (1971) indicated that an HTST recycle system would save 44% of the BOD normally generated in the pasteurization process. The BOD coefficient would be reduced

Table 8. Water Conservation Measures.[a]

Number	Description of Conservation Measures
1.	Adopt a definite water conservation program and make all personnel familiar with the program. The program should be discussed frequently in plant meetings and employees encouraged to make suggestions for further savings.
2.	From time to time a thorough study should be made to determine where additional water savings can be effected without sacrificing product quality or good housekeeping.
3.	Wherever economical, water used for cooling purposes should be re-used for other purposes or recirculated over a cooling tower, in a spray pond, or through an evaporative condenser.
4.	Only where cheap and abundant water is available should it be used for cooling and then discharged to a storm sewer or water course.
5.	Hot water should be supplied from a hot water tank rather than from mixing tees.
6.	Water running through hoses should be shut off when not in use.
7.	All hoses should be equipped with shut-off valves.
8.	Cleaning should be done by recirculation with re-use of cleaning solutions as long as they are effective.
9.	Wherever economical, condensate from heaters and overflows from hot water circulating systems should be returned to the boilers.
10.	Fix leaky water lines or valves as soon as leaks are detected.
11.	Eliminate product wastes due to leaks and spills to help reduce the amount of water needed for cleaning.

[a]MIF, 1967d.

from 0.80 to 0.45 pounds of BOD per 1000 pounds of milk processed. The recycle system would collect the diluted product-water mixtures during start-up, shutdown and product change-overs. Elliott (1977) has reported on such an installation in a new California dairy plant.

Harper _et al_. (1971) presented a modern system that eliminates intermediate process vats from processes of fluid milk products. The system utilizes the centrifugal machine in the form of the clarifier-separator in combination with the HTST system. Seiberling (1976) discusses this system in detail. Harper _et al_. (1971) pointed out that product change-overs are made product-to-product with no discharge to the drain and the elimination of the intermediate vats saves product losses with a BOD of 0.2 pounds per 1000 pounds of milk processed. Losses associated with the intermediate tanks for higher viscosity products such as cream may be 3.0 pounds of BOD per 1000 pounds of milk processed.

Elliott (1973) examined a number of new practices in dairy processing that relate to wastewater. He explained how CIP cleaning and welded pipeline systems have helped to reduce water use waste load and helped to automate dairy processing. He postulated that CIP cleaning was more efficient than hand cleaning and that welded pipeline systems were not subject to leaks at joints. CIP systems were explained as was the difference between the "throw-a-way" or single use system and the "re-use" system was explained. However, his conclusion that less water is used in a "re-use" type system was not confirmed by

Richter *et al*. (1975). They found for washing dairy transports, "re-use" type systems required more than 500 gallons per tanker while a single-use system only used 217 gallons per tanker with identical cleaning and sanitation.

Elliott (1973) described the collection of milk-water mixtures for use in dairy products or for animal feeding. He observed that through the use of air operated valves, level controls and a timed flow element a dairy plant could collect product-water mixtures and intermixed products. He explained that both of these mixtures were not legal milk products. He also explained how the first rinses from CIP circuits could be similarly collected. Elliott (1977) has described a plant utilizing both of these concepts.

The filling area is another area reviewed by Elliott (1973) for measures to conserve water and prevent product wastes from going into the plant wastewater system. He concluded that a plant recovery system was desirable to collect product from defective or damaged cartons. Conveyor lubricant usage in the filling area should be controlled as the lubricant contains about 25% hexane solubles (Elliott, 1973).

Municipal Discharge of Dairy Wastewaters

Municipal Charges

In their 1969 survey, Harper *et al*., 1971, found that 80% of the dairies discharging to municipalities paid a sewer charge. A sewer charge is a charge based on volume of water purchased and is usually 10-200% of the water bill (Carawan *et al*. 1972).

Some 7% of the dairy plants discharging to municipalities were found to be also paying a surcharge. A surcharge is an additional charge based on strength of the wastewater constituents such as BOD or SS (Carawan et al. 1972).

Often surcharges are computed on the pounds of a wastewater constituent exceeding those found in normal domestic wastewaters (Anon., 1972). Normal domestic wastewaters usually have the following composition (Metcalf and Eddy, 1972):

BOD	100-300 mg/l
COD	250-1000 mg/l
SS	100-350 mg/l
FOG	50-100 mg/l

Carawan et al. (1972) predicted the municipal costs for a multi-product dairy. Total municipal costs for water use, sewer charge and surcharge totaled approximately $10,000 per month for a plant producing an average of 500,000 pounds of product for each of 22 working days. Water and sewer charge were approximately $1,500 and the remaining $8,599 was surcharge.

Industrial User Ordinance

A trend of municipalities setting limits on industrial wastewater discharges at levels commonly found in domestic waste was uncovered during the national dairy wastewater survey (Harper et al. 1971). The survey team concluded that dairy plants cannot possibly meet these standards with present technology. Thus, the construction of separate treatment facilities was predicted to be inevitable if the trend continues. For example, the Metropolitan Sanitary District of Chicago in 1973 put a restriction on municipal discharge of 100 mg/l of hexane extractable fats, oils and greases (Lassus and Selitzer, 1977).

The limits on restrictions on industrial wastewater discharge are usually found in an industrial user ordinance. Massey (1976) has reported on the requirement for industrial user ordinances by the Environmental Protection Agency. Model ordinances are available (Cleary, 1971; Anon., 1972; CWPCA, 1974; Soltow, 1975; WPCF, 1975; WPCF, 1976; and Peck and Gordon, 1977).

System Analysis

Operations Research

Operations research is a term widely used to describe analyses of all types of systems (Ward, 1971). Operations research is a truly interdisciplinary field for the study of systems. Systems analysis, process analysis, systems engineering and operations research have all been used to describe ways and means of analyzing systems.

Himmelblau and Bischoff (1968) have defined system as "the assemblage of elements(abstract and arbitrary divisions of the process) which is tied together by common flows of materials and/or information. The output of a system is a function not only of the characteristics of the elements of the system, which are also known as subsystems, but also of their interactions and interrelations". This definition can be related directly to a dairy processing plant.

Linear Programming

Linear programming (LP) is a special branch of operations research. LP can be defined as an optimization tool, using linear approximations of functional relationships, which is concerned with identifying courses of action which will optimize (maximize or minimize) some stated goal (revenue, profit, cost). Ferguson and Sargent (1958) defined LP as a technique for specifying how to use limited resources or capacities of a business to obtain a particular objective, such as least cost, highest margin, or least time, when these resources have alternative uses.

Ferguson and Sargent (1958) credit the beginning of linear programming to Leon Walras in 1874. However, George B. Dantzig was acknowledged as being responsible for LP as we know it today for he developed the simplex method in 1947 for the solution of linear programming problems.

There are numerous texts with sections entirely concerning LP applications and techniques. Several of these include van de Panne, 1971; Beneke and Winterboer, 1973; Ferguson and Sargent, 1958; Thompson *et al*., 1976; Russell, 1973; Bender *et al*., 1976; IBM, 1964; IBM, 1969a and Heady and Candler, 1969.

Facts for making better management decisions are often difficult to interpret. Ferguson and Sargent (1958) explained that linear programming has a significant advantage in determining how to use limited amounts of resources. Van de Panne (1971) noted that linear programming can be used in almost any industrial operation.

Linear programming helps a manager select the best plan by considering all the alternatives (Ferguson and Sargent, 1958). The simplicity of linear programming after model formulation enables managers to test a wide range of alternative adjustments and to analyze the consequences with limited managerial time. Ferguson and Sargent (1958) presented difficulties that arise in developing models for LP analysis. These difficulties included cost coefficients that can not be formulated, input-output relationships (activity coefficients) that must be estimated for the model, restraints that are difficult to specify and that the solution of large problems would be almost impossible without the aid of a computer.

<u>Mathematical Description</u> Linear programming is a systematic method of maximizing a linear objective function subject to restraints imposed by one or more linear inequalities (Walker, 1975). Walker noted that the linear function to be maximized (or minimized) is called the objective function where:

$$f = \Sigma_j \, c_j \, X_j \qquad , \; j = 1,2,....,n$$

or $$f = c_1 X_1 + c_2 X_2 + ... + c_n X_n$$

f = value to be maximized or minimized (objective function)

X_j = variable - unknown to be determined (activity)

c_j = effect on f of a unit change in X_j (cost coefficient)

$X_j \geq 0$, non-negativity required for all activities

The constraints (restrictions) subject to which the objective function is maximized or minimized can be distinguished by equality or inequality constraints.

$$(\text{Max}(\text{min})\ f \text{ subject to:}$$

$$b_i \overset{\geq}{\underset{\leq}{=}} \sum_j a_{ij}\, X_j \qquad , \ i = 1,2,\ldots.m$$

b_j = constant, i.e., supply of resource (right hand side)

a_{ij} = input-output coefficient, effect on b_i of a unit change in X_j (coefficient)

Values for each c_j, a_{ij} and b_i must be known or assumed.

Walker (1975) defined a "feasible solution" as the term applied to any set of X_j that satisfies the constraints (b_i). Further an "optimal feasible solution" is any feasible solution which optimizes the objective function. The purpose of an LP solution is to find an optimal feasible solution (Ward, 1970).

Use of Linear Programming. Thompson *et al*. (1976) used linear economic models of water use and wastewater treatment to examine how managers in the chemical industry (ammonia, alkali and chlorine) would respond to a government policy of zero discharge of pollutants. They used linear programming techniques to examine the cost in terms of water, fuel and raw materials of complying with such a policy. They detailed tradeoffs and substitutions necessary to comply. Specifically, they answered questions concerning:

1. Process changes
2. Wastewater treatment process changes
3. Cost increases to obtain zero pollutant discharge

to wastewater

4. Air and land pollutant discharge resulting from zero pollutant discharge of wastewater

The analysis by Thompson *et al.* (1976) demonstrated the effectiveness of the linear programming format. Production costs with zero discharge of pollutants were increased 3% for ammonia plants, 5.6% for chlor-alkali plants and 7.7% for ethylene plants. A control on dissolved solids was the most effective method of achieving zero discharge of pollutants.

A feature claimed by Thompson *et al.* (1976) for their linear models was that they synthesized important technical data into a comprehensive economic analysis. They postulated that this provides a basis for evaluating the effects of possible governmental policy decisions on the use of resources, the discharge of wastes and the cost of production before the policy decisions are made. Management response to policy change can also be evaluated. Thompson *et al.* (1976) indicated management response can be any or all of the following changes: (1) In production processes, (2) In resources use, (3) In treatment technologies or (4) In management procedures.

Ward (1970) and Ward *et al.* (1972) presented a network analysis of water and waste process changes in a poultry processing plant. Annual returns of changes ranged from 6.2 to 49% on investment as fresh water costs varied from $0.1 to $1 per 1000 gallons. A special application relating specifically to the dairy industry involved the selection of the optimum product line. Snyder and French (1958) indicated that no "one best" line existed but that a number of alternatives were available with little change in daily net return. Key resource restrictions included cold room capacity, working capital and plant labor. Carrawan (1977) reviewed a number of other linear programming applications which were found to not relate directly to this study.

OBJECTIVES AND SCOPE OF INVESTIGATION

The primary objective of this study was to develop an analysis procedure for a Case Study multiproduct dairy processing plant producing fluid milk products, cottage cheese and ice cream which could lead to management least cost solutions for water and waste related costs. Water and waste related costs include water, sewer, surcharge and product loss. Alternative process schemes reviewed included changes for water reuse, product loss prevention, the recovery of product and formerly wasted product water mixtures for use in ice cream production and the collection of a segregated waste for animal feed or disposal.

A major goal of this study was to develop a linear economic model of the Case Study Plant using a limited number of alternative processes. Linear programming was thought to be an excellent tool to efficiently study the multitude of water and waste related alternatives known to be applicable in dairy processing. This study was limited to the initial development of the model and trial solutions of the analysis technique for minimizing water and waste related costs.

The research also evaluated external restraints that might be imposed on a dairy processing facility which relate to water and waste such as the influence of maximum BOD and FOG restrictions. Sales demand was selected as the controlling element for the Case Study Plant.

Utilizing literature information, data obtained from operating dairies and estimates from knowledgeable individuals, investigations were conducted to establish the following:

1) A case study dairy plant for processing fluid milk, cottage cheese and ice cream.
2) Water and waste reduction practices known to reduce water use or waste load.
3) Process alternatives know to reduce water use and waste load.
4) A linear programming model to evaluate water and waste related activities in the case study dairy.

Specific objectives included the following:

1) To specify inputs and products, including composition, for the Case Study Plant.
2) To specify operating parameters for the Case Study Plant.
3) To develop costs, coefficients, resource limitations and restrictions for use in the linear programming model for each alternative process.
4) To develop engineering flowgraphs of the production processes.

5) To calculate the effect of selected process alternatives on water use.

6) To relate the impact of municipal sewer use ordinance restrictions on the operation of the Case Study Plant.

7) To itemize the role of water and waste related costs on the cost of producing dairy products in the Case Study Plant.

8) To examine the role of management in the control of dairy processing water use and wastewater discharge.

9) To verify that the linear analysis model represents the developed operating parameters, costs, coefficients, resource limitations and restrictions for the Case Study Plant.

10) To determine optimal solutions for the linear analysis model.

11) To outline needs for refinement of the linear analysis model.

The approach of this study considered the evaluation of cost, water use and wastewater discharge through process modifications. The Case Study Plant was assumed to be either a planned new facility or an extensively renovated existing facility. This assumption allowed the incorporation of process alternatives which minimize or avoid water using or polluting processes.

EXPERIMENTAL PROCEDURES AND METHODOLOGY

Introduction

The Case Study Plant was developed to represent a typical, medium sized operating multiproduct dairy plant. The products proposed to be produced in the multiproduct plant included fluid milk products, ice cream, cottage cheese and drinks.

The development of an analysis scheme for the study of least cost solutions for water and waste related costs in the case study dairy was accomplished in two distinct segments. First, a study of possible changes, the identification of the cost of these changes and the effect of the changes on plant costs was developed and has been reported by Carawan (1977).

Second, the development of a linear analysis model of the case study plant was initiated and the development reported by Carawan (1977). Information from the initial part of the study was used with linear programming techniques in the development of the linear analysis model.

Case Study Plant

A case study plant was selected and designed for the purpose of this study. The plant was designed to produce fluid milk products, cottage cheese, ice cream and drinks because these products are representative of the typical multiproduct dairy. The plant has all related plant operations generally associated with dairy plants including offices, garages and the needed service facilities. In Figure 1 is presented a schematic overview of the dairy processing plant as considered for this study.

There are four basic plant divisions. There is the fluid products processing area (FP), the cottage cheese processing area (CC), the ice cream processing area (IC) and the related plant operations (OTHER). By-product recovery operations such as whey recovery, fines recovery and rinse recovery which will be described later in this study.

Basic plant inputs included raw milk (RM), labor (LABOR), ingredients (INGRE), materials (MATL), water (WAT), electricity (ELEC) and capital (CAPITAL). Plant outputs included products including fluid milk products (FM), fruitade (FA), orange juice (OJ), sour cream (SC), buttermilk (BM), cottage cheese (CC) and ice cream (IC). Other outputs included municipal discharge (SEWER), storm sewer (SSEWER), animal feed (ANIMF) and segregated waste for disposal by truck (TRUCK).

The decision points as shown on Figure 1 represent a location on the schematic where a decision must be made. For example, there is a decision point indicated between ANIMF and TRUCK on the schematic. This indicates that a decision must be made on how much of the input to that decision point will go to ANIMF and TRUCK.

Plant Operating Assumptions

There are an infinite number of factors which can relate to an operation as large as the Case Study Dairy. For that reason, only factors that were thought to be necessary for this study

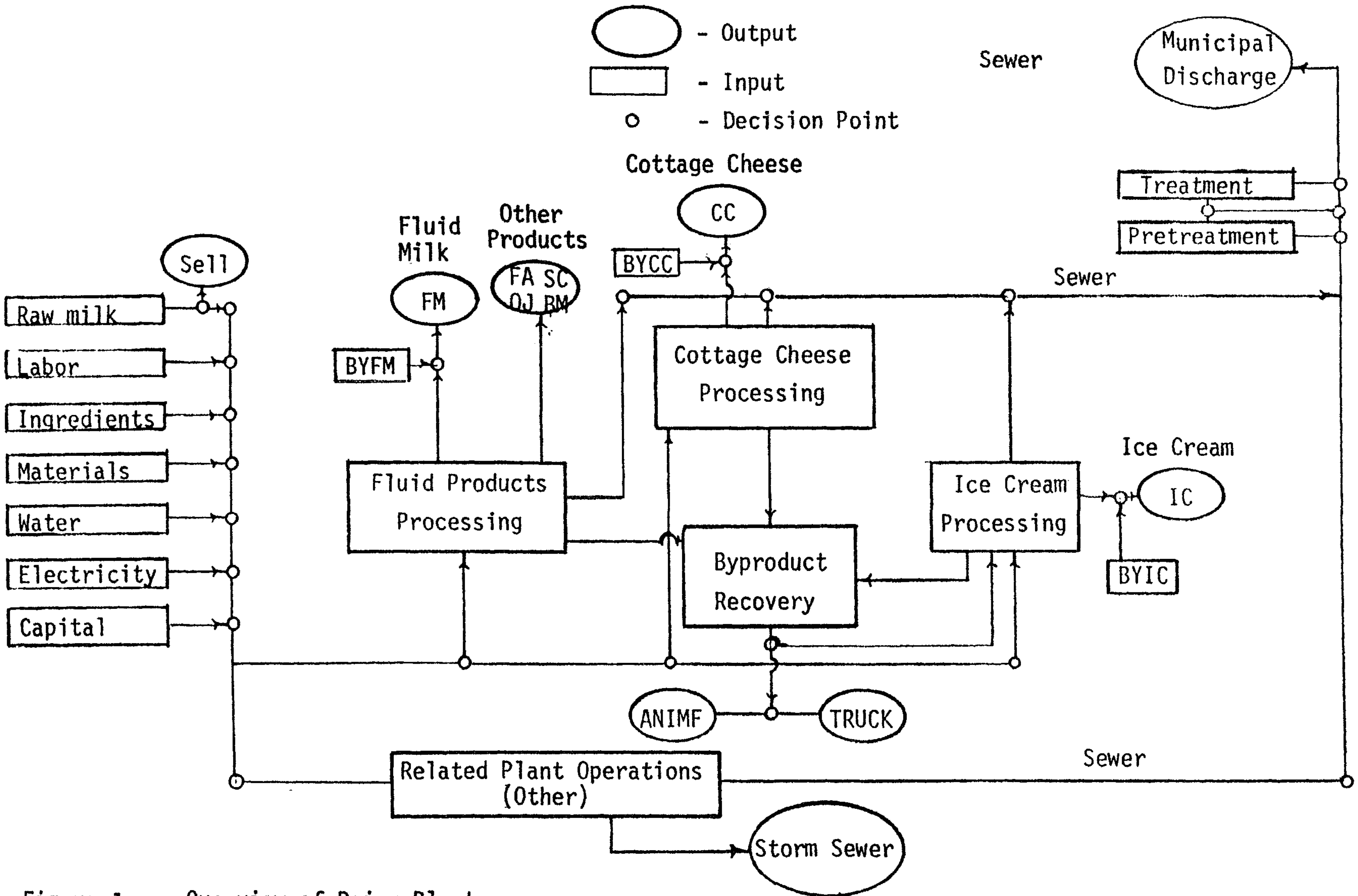


Figure 1. Overview of Dairy Plant.

were selected and analyzed.

Raw Products. Raw products available for use in the plant included whey (WH), returns of fluid milk products (RT), high solids recovery (RH), raw milk receipts (RM), cream (CM), skimmilk (SM), butteroil (BO), condensed skim (CS), liquid cane sugar (LS), liquid corn syrup - 32DE42 (LC), skim powder (SP), whey powder (WP) and buttermilk powder (BP). The average composition of these products is given in Table 9. The computer codes are given to help with the model formulation. The average compostion of the raw milk received was assumed to be 3.8% butterfat and 8.66% milk-solids-not-fat, after reviewing raw milk composition in Henderson (1971).

Size and Operation Schedule. The plant was designed to accomodate an average of 500,000 lb/day of raw milk receipts. The raw milk was assumed to be delivered on a 6-day schedule by 5500 gal raw milk tankers.

Production was predicted using an assumed average of 3.0 million lb/wk of raw milk receipts. The plant was designed to process products on a 5-day schedule. Using the general rule of allowing for approximately 50% expansion recommended by dairy designers, the floor space was assumed to be large enough to accommodate added equipment allowing the plant capacity to increase to receive and accommodate 5.0 million lb/wk of raw milk receipts.

Bulk Deliveries. The Case Study Plant was designed to accommodate bulk deliveries of materials and ingredients other than raw milk and cream. Bulk cleaning solutions, liquid corn

Table 9. Average Composition of Raw Products.

Raw Products (Code)	BF[e]	Total Solids	MSNF	Lactose	Ash	Protein	Water
				(%)			
Whey WH[a]	--	.061	.061	.045	.008	.008	.939
Returns RT[b]	.02	.1175	.0975	.0525	.0076	.0374	.8825
Recovery RH[b]	.015	.06	.045	.024	.004	.02	.94
Cream CM[d]	.40	.4535	.0535	.0288	.0042	.0205	.5465
Skim Milk SMd	.0001	.0901	.09	.0484	.0071	.0345	.9099
Butteroil BO[d]	.99	.99	--	--	--	--	.01
Raw Milk RM[c]	.038	.1246	.0866	.0466	.0068	.0332	.8754
Condensed Skim CS[d]	--	.28	.28	.1507	.0220	.1074	.72
Liquid Sugar LS[d]	--	.67	--	--	--	--	.33
Liquid Corn LC[d]	--	.7764	--	---	--	--	.2236
Skimmilk Powder SP[d]	--	.97	.97	.5220	.0761	.3719	.03
Whey Powder WP[d]	.011	.93	.93	.735	.0730	.3566	.07
Buttermilk Powder BP[d]	.053	.96	.91	.4897	.0714	.3489	.04

[a]Webb and Whittier, 1970

[b]Code 03 and estimation

[c]Assumed

[d]Frandsen and Arbuckle, 1961

[e]Butterfat

[f]Milk-solids-not-fat

syrup and liquid cane sugar and condensed skim could all be received by tank truck. Surplus milk and cream could be shipped by tank truck.

Product Formulation. Products to be produced by the plant included skim (SK), low fat (LF), homogenized - 3.25 BF (HO), half-n-half (HH), chocolate (CH), buttermilk (BM), sour cream (SC) fruitade (FA), orange juice (OJ), cottage cheese (CC), dressing (DS), curd (CD) and basic ice cream (IC). These included finished products and intermediate products as they were generated in the course of processing. Product compositions from which formulations were calculated are shown in Table 10. The compositions were selected after a review of the ranges of compositions for products presented by Henderson (1971) and for ice cream by Frandsen and Arbuckle (1961).

Product Production. Fluid milk products comprized the largest segment of production for the case study plant and accounted for 92% of the plant production. Fluid milk products produced included skim milk (SK), 2,000,000 lb/yr; low fat (LF), 16,000,000 lb/yr; homogenized (HO), 59,000,000 lb/yr; half-n-half (HH), 2,200,200 lb/yr; chocolate (CH), 12,000,000 lb/yr; buttermilk (BM), 4,500,000 lb/yr; and sour cream (SC), 500,000 lb/yr.

Cottage cheese (CC) production was 1,500,000 lb/yr. Ice Cream production was 5,000,000 lb/yr. Drinks produced were fruitade (FA), 2,000,000 lb/yr and orange juice (OJ), 750,000 lb/yr.

The total production assumed for the Case Study Plant ranged

Table 10. Assumed Products Composition.[e]

Product Code	Component								
	BF[f]	MSNF[h]	Lactose[a]	Ash	Protein	Other	Sugar	TS[g]	Water
	(%)								
Skim SK	.001	.100[b]	.0538	.0088	.0374			.1010	.899
Low Fat LF	.015	.097[b]	.0520	.0088	.0362			.1116	.888
Homogenized HO	.0325	.087	.0468	.0076	.0326			.1195	.880
Half-n-Half HH	.105	.078	.0420	.0068	.0292			.1830	.817
Chocolate CH	.010	.088	.0474	.0077	.0329	.02	.06	.178	.822
Buttermilk BM	.021[c]	.107	.0574	.0097	.0399			.1071	.893
Sour Cream SC	.187	.09	.0484	.0079	.0337			.275	.725
Fruitade FA	-	-	-	-	-	.02	.06	.0800	.910
Orange Juice OJ	-	-	-	-	-	.11	-	.1100	.89
Cottage Cheese CC	.040[d]	.177	.0290	.0100	.1362			.2170	.783
Dressing DS	.140	.076	.0409	.0123	.0228			.2160	.784
Curd CD	.003	.207	.0270	.0100	.1700			.2100	.790
Ice Cream IC	.100	.100	.0538	.0088	.0374	.003	.15	.3530	.647

[a]or lactic acid [b]MSNF added, 1% [c]Butterfat added, 2% [d]Dressing added, (14% BF)
[e]Estimated by authors [f]Butterfat [g]Total solids [h]Milk-solids-not-fat

from 104,250,000 lb/yr to 115, 700,000lb/yr. The composition of the products was presented in Table 10. Other products such as yogurt and frozen novelties would probably be processed in a typical multiproduct dairy. However, the products selected were those representative of the processing sequence though to be most important by these investigators in terms of water and waste related parameters. The yearly production of products other than those selected would be expected to be relatively small.

Calculated BOD Values. Estimated values for BOD as concentration and as lb BOD/lb product were calculated for plant raw ingredients and finished products. The estimated values were calculated from the composition as suggested by Harper *et al.* (1971). The values are displayed in Table 11.

Calculated Weights. Volume-weight relationships used for milk products throughout this study were calculated from the following equation:

$$\frac{100}{100 + (\%BF \times 0.03928) - (\%\ SNF \times 0.39221)} \times 8.3364$$

which was developed for determining the weight of milk products at 40 F (USDA, 1965).

Processes and Equipment

Jones and Harper (1976) noted that although smaller plants tend to use batch instead of continuous processes, processing operations for fluid milk involve some or all of the following steps:

(1) Receiving and storage (RC, ST)

(2) Centrifugal operations [clarification (CL), separation (SP)]

Table 11. Calculated[a] BOD_5 Values.

Product	Code	Fat	Protein	Sugar[b]	BOD_5	
		(Decimal %)			(mg/l)	(lb BOD_5/lb product)
Skim	SK,SM	.0010	.0374	.0538	74,380.	.074
Low Fat	LF	.0150	.0362	.0520	84,400.	.084
Homogenized	HO	.0325	.0326	.0468	92,900.	.093
Half-n-Half	HH	.1050	.0292	.0420	151,000.	.151
Chocolate	CH	.0300	.0329	.1074	130,000.	.130
Buttermilk	BM	.0200	.0399	.0574	96.200.	.096
Sour Cream	SC	.1850	.0337	.0484	231,000.	.231
Drinks	FA	---	---	.0800	52,000.	.052
Orange Juice	OJ	---	---	.1100	71,000.	.072
Cottage Cheese	CC	.0400	.1362	.0290	195,000.	.195
Dressing	DS	.1400	.0228	.0409	175,000.	.175
Curd	CD	.0030	.1700	.0270	195,000	.195
Ice Cream	IC	.1000	.0374	.2038	260,000.	.260
Whey (No Fines)	WH	.0000	.0080	.0450	37,500	.037
Whey (Fines)	WF	.0001	.0280	.0464	59,000.	.059
Returns	RT	.0200	.3074	.0525	90,000.	.090
High Solids Recovery	RH	.0150	.0200	.0240	50,000.	.050
Receipts	RM	.0380	.0332	.0466	98,000.	.098
Cream	CM	.4000	.0205	.0288	396,000.	.396
Liquid Cane	LS	---	---	.6700	436,000.	.436
Corn Syrup	LC	---	---	.7764	505,000.	.505
Condensed Skim	CS	.0030	.1048	.1507	209,000.	.208

[a] BOD_5(mg/l) = 10,000[89(D% Fat) + 65(D% Sugar) + 103 (D% Protein)] as presented by Harper _et al._, 1971 where D% = Decimal %.

[b] Sugar = Lactose, Corn Solids, Sucrose, Lactic Acid

(3) Standardization (SD)

(4) Pasteurization (HT)

(5) Flavor treatment (FT)

(6) Homogenization (HO)

(7) Packaging (FF)

(8) Storage (SF)

(9) Distribution (DT)

These and the processes specifically for cottage cheese and ice cream were evaluated for their role in water and related costs.

Receiving. Receiving operations for the case study dairy are presented in Figure 2. Receiving operations for fluid milk plants were reviewed by Jones and Harper (1976). Receiving for the Case Study Plant was based on their observations. Jones and Harper noted that three basic phases of receiving include: (a) preparation for unloading, (b) unloading and (c) cleaning. They also discussed in detail the process of inventory control. The payment of milk by farm bulk tank measurement was noted. Also, they reported on the common practice of dairies to check the bulk tank content by: (1) weighing tankers, (2) weighing receiving tanks, (3) metering or (4) liquid-level measurement in storage tanks.

Equipment selected for receiving in the case study plant is listed in Table 12. Raw tanks include 3-35,000 gal silos. Cleaning of the tankers, raw tanks and raw lines was assumed by one CIP system.

Centrifugal Operations. The Case Study Plant was designed

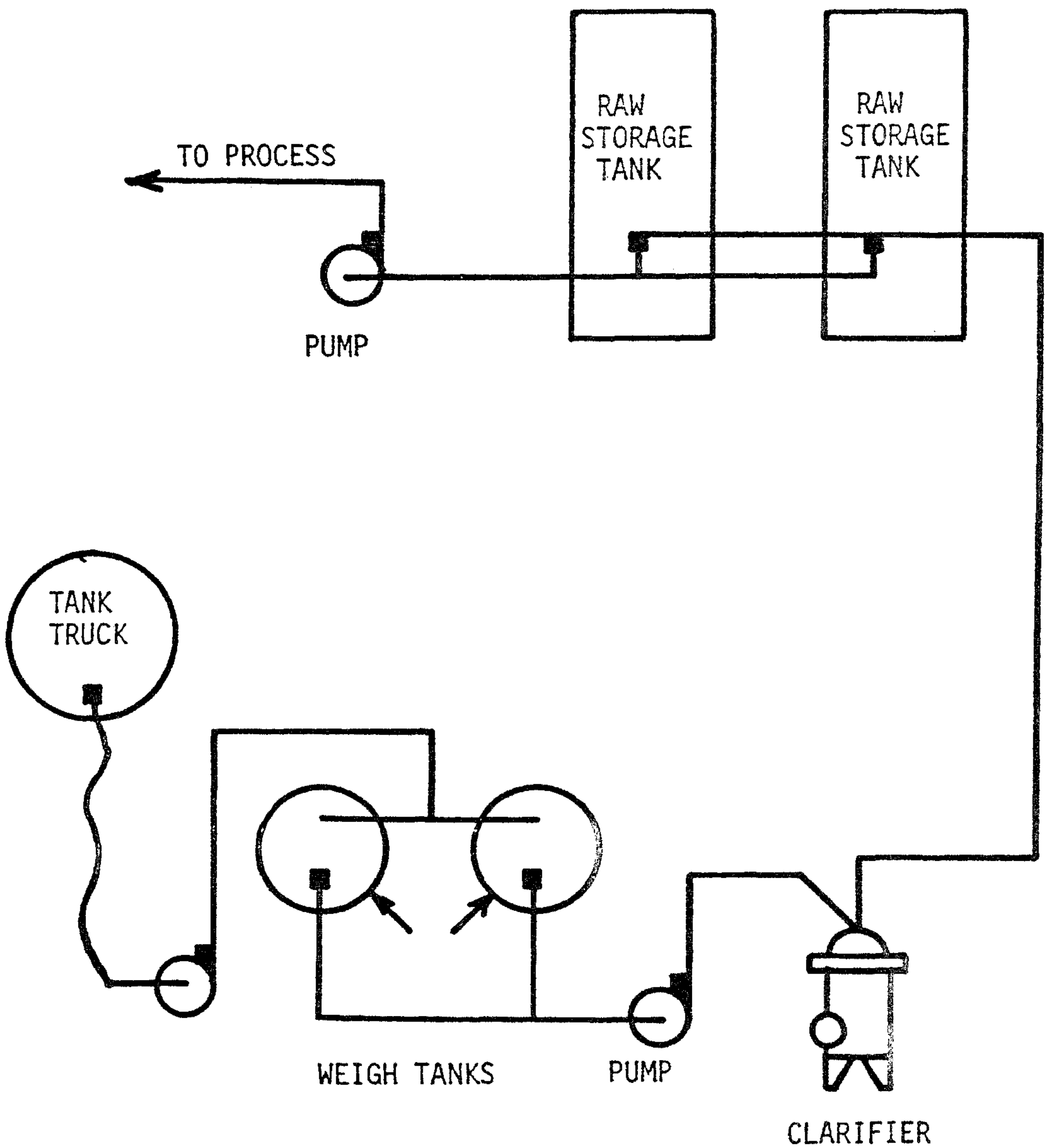


Figure 2. Receiving Operations.

Table 12. Major Equipment List for Case Study Plant.

Number	Equipment	Size	
Pasteurizers			
1	Larger indirect, plate heat exchanger (HTSTL)	60,000 lb/hr	with: (a) Flavor standardization (b) Homogenizer (c) 90% Regeneration
1	Smaller indirect, plate heat exchanger (HTSTM)	20,000 lb/hr	with: (a) Flavor standardization (b) Homogenizer (c) 80% Regeneration
2	Vat processors	2,500 gal	
Centrifugal Machines			
1	Clarifier	60,000 lb/hr	
1	Separator	60,000 lb/hr	
Fillers			
1	Bulk (10 quart container)	10/min	
2	Paper (Half-gallon)	80/min each	
2	Paper (Quart, pint, half-pint)	110/min each	
1	Plastic (Gallon and half-gallon jugs)	40/min	
1	Ice cream (Half-gallon)	150/min	
1	Cottage Cheese (Pint)	80/min	
Tanks			
3	Silos	35,000 gal	raw milk
2	Silo	20,000 gal	standardizing, pasteurized surge
4	Horizontals	10,000 gal	ingredients
1	Horizontal	2,500 gal	raw cream
4	Horizontals	10,000 gal	surge

Table 12. Major Equipment List for Case Study Plant continued.

Number	Equipment	Size	Explanation
1	Horizontal	2,500 gal	cream
1	Horizontal	10,000 gal	liquid sugar
1	Horizontal	10,000 gal	liquid corn
<u>Cottage Cheese</u>			
4	Vats	3,000 gal	
<u>Cleaning</u>			
1	CIP System		raw tankers, tanks and lines
1	CIP System		product tanks and lines
<u>Utilities</u>			
2	Boilers	300 BHP/each	
3	Air Compressors	100 HP/each	
6	Refrigeration Compressors	1200 T Total	
60	Hose Stations		
<u>Transportation</u>			
100	Trucks		

with both a clarifier and a separator each of 60,000 lb/hr capacity. Jones and Harper (1976) reviewed the operation of both machines. The clarifier was placed as shown in Figure 2 and the separator was placed as shown in Figure 3.

Pasteurization. The products produced by the multiproduct dairy required the utilization of several pasteurization methods. Jones and Harper (1976) reviewed the various methods of pasteurizing fluid milk products. Two indirect heat exchanger pasteurizers (HTSTL and HTSTM) and two vat processors for batch pasteurization were selected as listed in Table 12.

The products processed on the larger pasteurizer (HTSTL -- 60,000 lb/hr) would include homogenized milk, skim, low fat and chocolate. The time-temperature selected for pasteurization was 170 F for 15.5 sec. Product pasteurized on the smaller pasteurizer (HTSTM - 20,000 lb/hr) included cream, half-n-half, and ice cream mix. The time-temperature relationship selected for the smaller unit was 175 F for 15.5 sec. Batch pasteurization was planned in the vat processors for buttermilk, sour cream and milk for cottage cheese. All pasteurization temperature-time relationships selected were above the minimum pasteurization requirements.

Vacuum flavor standardization systems as described by Jones and Harper (1976) were selected to be installed on both HTST system. Both HTST systems also were designed with properly sized homogenizers as a part of the HTST system.

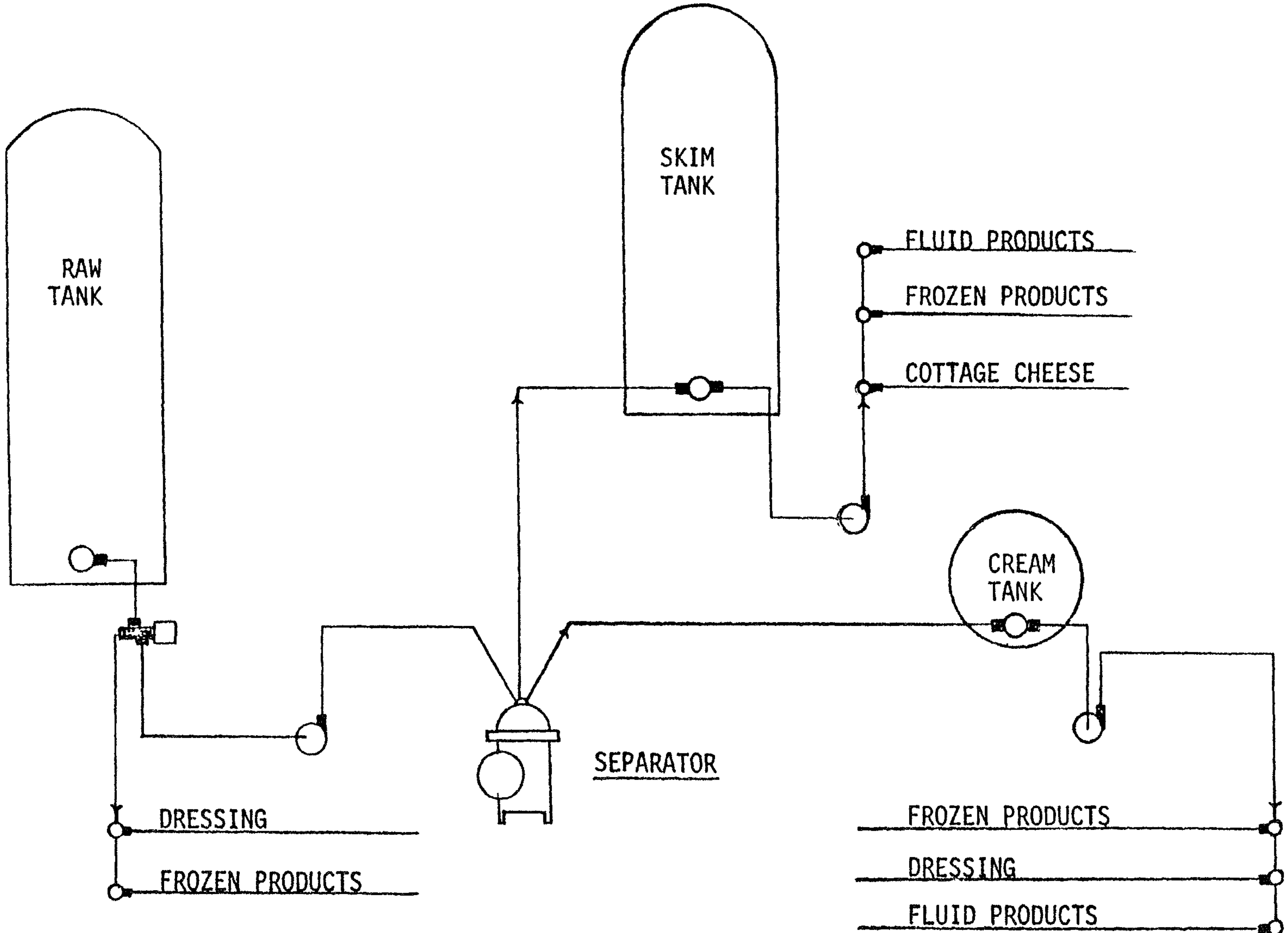


Figure 8. Schematic of Fluid Milk Delivery to Processing for Case Study Plant.

Filling. The Case Study Plant was designed with six fillers for fluid milk products such as homogenized, skim, low fat, chocolate as well as the drinks, fruitade and orange juice. As listed in Table 12, the plant was equipped with four fillers for gable-top, plastic coated cartons. Two of these were specifically for half-gallon containers with capacities of 80 containers/min each. Two were for quarts, pints and 1/2 pints and were capable of filling 110 containers/min each. A bulk filler was selected for 10-quart dispensing containers with a capacity of approximately 10 containers/min. The sixth fluid filler was for gallon and half-gallon plastic jugs. This machine was capable of filling 40 jugs/min. The Case Study Plant was assumed to buy molded jugs.

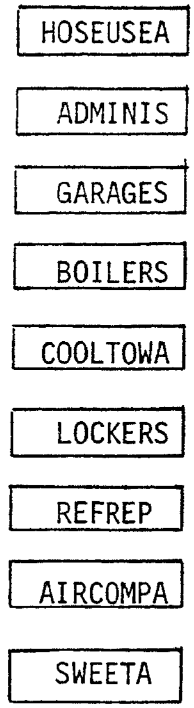
The fillers described would be similar to those found in most any dairy plant filling the products described. Not specified are the casers and stackers which would be vital to the fluid milk operation. These were not specified because they do not use water and the wastes created were included in the filling process.

Cottage cheese and sour cream were to be packaged on a filler that was of the cup fill design such as those used for ice cream. The approximate speed of the machine is 80 units/min. This would be the type of machine to be expected in a modern dairy. Bulk filling of cottage cheese and sour cream was by pump with a hand operated switch and nozzle.

Ice cream was designed to be packaged only in half-gallon containers. The machine selected was a high speed type filler with a filling rate of 150 half-gal/min. A commercial dairy would probably differ in that cup and novelty fillers would be required. These were not included for the Case Study Dairy because realistic water and waste coefficients were not available for such operations.

Production and Non-Production Processes. The production of fluid milk products, cottage cheese and ice cream requires a number of operations or activities. Special attention will be given to those processes using water or contributing to the wastewater load. The processes selected may not be all inclusive and may not always be presented in a normal processing sequence but will be organized to provide a processing scheme allowing for the study of water and waste related parameters. There are a number of water and wastewater activities that are necessary for normal plant operation. The most significant of these are diagrammatically presented in Figure 4.

Related Plant Operations. A number of processes that could not be assigned to a specific product area were combined with the ancillary activities for the Case Study Plant. An example of a process that could not be assigned to a specific product area would be receiving. Receiving represents more than one activity as it encompasses not only receiving of raw milk but also the receiving of liquid sugars, condensed skim, cream and cleaning materials. Also associated with receiving would be the CIP and COP activities necessary for the proper sanitation of the equipment, lines and tanks in the receiving area. The ancillary processes necessary for the operation of the Case Study Plant are shown in Figure 4. They included hose stations (HOSEUSEA), plant



Code	Activity
HOSEUSEA	Supply water for hose stations
ADMINIS	Area used by plant administration and sales personnel
GARAGES	Maintenance of trucks
BOILERS	Supply steam for heating and process demands
COOLTOWA	Facilities for recycle of water through cooling tower(s)
LOCKERS	Shower and restroom facilities for processing employees
REFREP	Facilities for repairing sales display cases
AIRCOMPA	Supply compressed air for processing
SWEETA	Supply chilled water supply (34F) for processing needs

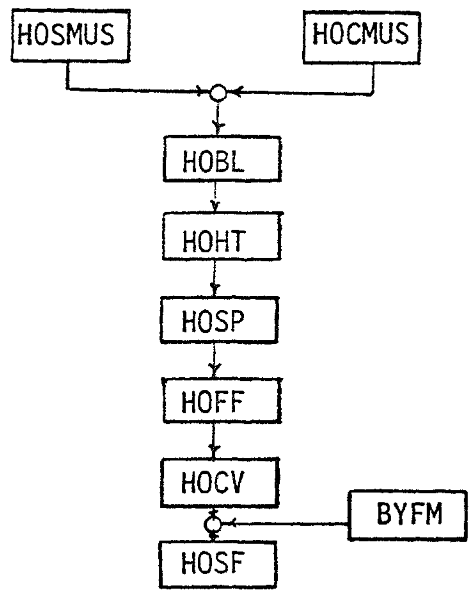
Figure 4. Ancillary processes with computer designations.

sales and administration area (ADMINIS), truck maintenance facility (GARAGES), boilers (BOILERS), cooling towers (COOLTOWA), employee shower and restroom facilities (LOCKERS), sales display case repair (REFREP), air compressors for air supply (AIRCOMPA) and a chilled water supply system (SWEETA). Other activities that were non-specific for product processing included lubrication system for conveyors and water use in coolers.

These non-production processes that included activities that were non-product process related and the ancillary functions for the Case Study Plant were grouped together as related plant operations (Figure 1). They were represented by computer code either as OTHER or ETC...

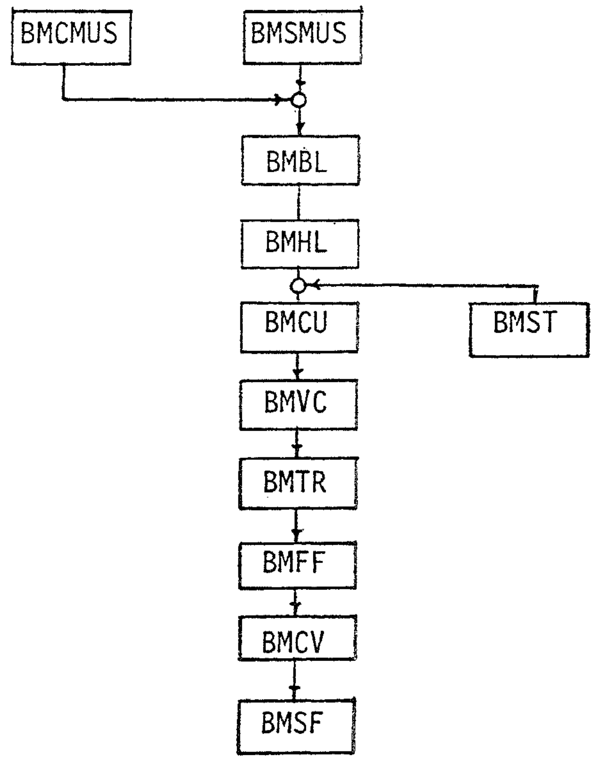
Fluid Milk Processing. The fluid milk processing sequence as shown for homogenized milk in Figure 5 is representative of the processing for skimmilk (SK), homogenized (HO), low fat (LF), chocolate (CH), half-n-half (HH) and cream (CM). The process sequence for homogenized milk processing begins with the transfer of raw milk, cream or skim to a blend tank (HOBL), followed in order by pasteurization (HOHT), pasteurized storage (HOSP), filling (HOFF), casing, stacking and conveying (HOCV) and finally storage in the refrigerated storage (HOSF). In the event that homogenized milk could not be processed due to some restriction imposed in the modeling process, the availability of homogenized milk already cartoned (BYFM) was allowed to meet sales demands.

Buttermilk Processing The processing of buttermilk requires a special process sequence as shown in Figure 6. The major differences between buttermilk and fluid milk processing is that



Code	Activity
HOSMUS	Skim milk supply
HOCMUS	Cream supply
HOBL	Blending of cream and skim
HOHT	High, Temperature, Short, Time Pasteurization
HOSP	Pasteurized storage
HOFF	Filling
HOCV	Conveying and casing
HOSF	Refrigerated storage
BYFM	Buy cartoned fluid milk products

Figure 5. Process sequence for fluid milk products with computer code designations for homogenized milk.



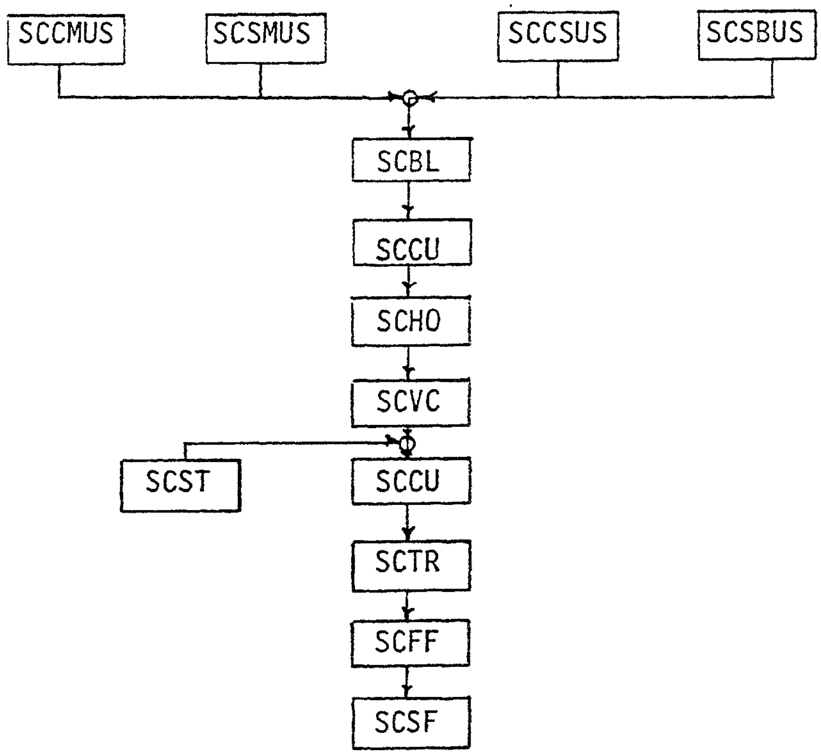
Code	Activity
BMCMUS	Supply cream
BMSMUS	Supply skim
BMBL	Blend
BMHL	High, Temperature, Short, Time Pasteurization with Extended Holding Tube
BMCU	Culturing
BMVC	Vat cooling
BMTR	Pumping
BMFF	Filling
BMCV	Conveying and casing
BMSF	Refrigerated storage
BMST	Prepare and supply starter

Figure 6. Production processes for buttermilk with computer code designations.

vat pasteurization is used, starter must be produced and a culturing step is added. The procedures recommended by Henderson (1971) were adopted for the Case Study Plant. Cream (BMCMUS) and skimmilk (BMSMUS) are combined (BMBL) to provide 2% fat. The milk is then vat pasteurized at 190 F for 30 min (BMVP), a 0.5% starter inoculum is added (BMST), and the starter-milk mixture is cultured at 71 F $\pm$ 1 F for 12-15 hr (BMCU). The buttermilk is cooled to 45 F (BMVC) and held for 1-3 hr to allow air to escape the mixture and then transferred (BMTR) to the filler and filled (BMFF). The containers are stacked and conveyed (BMVC), and finally sent to storage (BMSF).

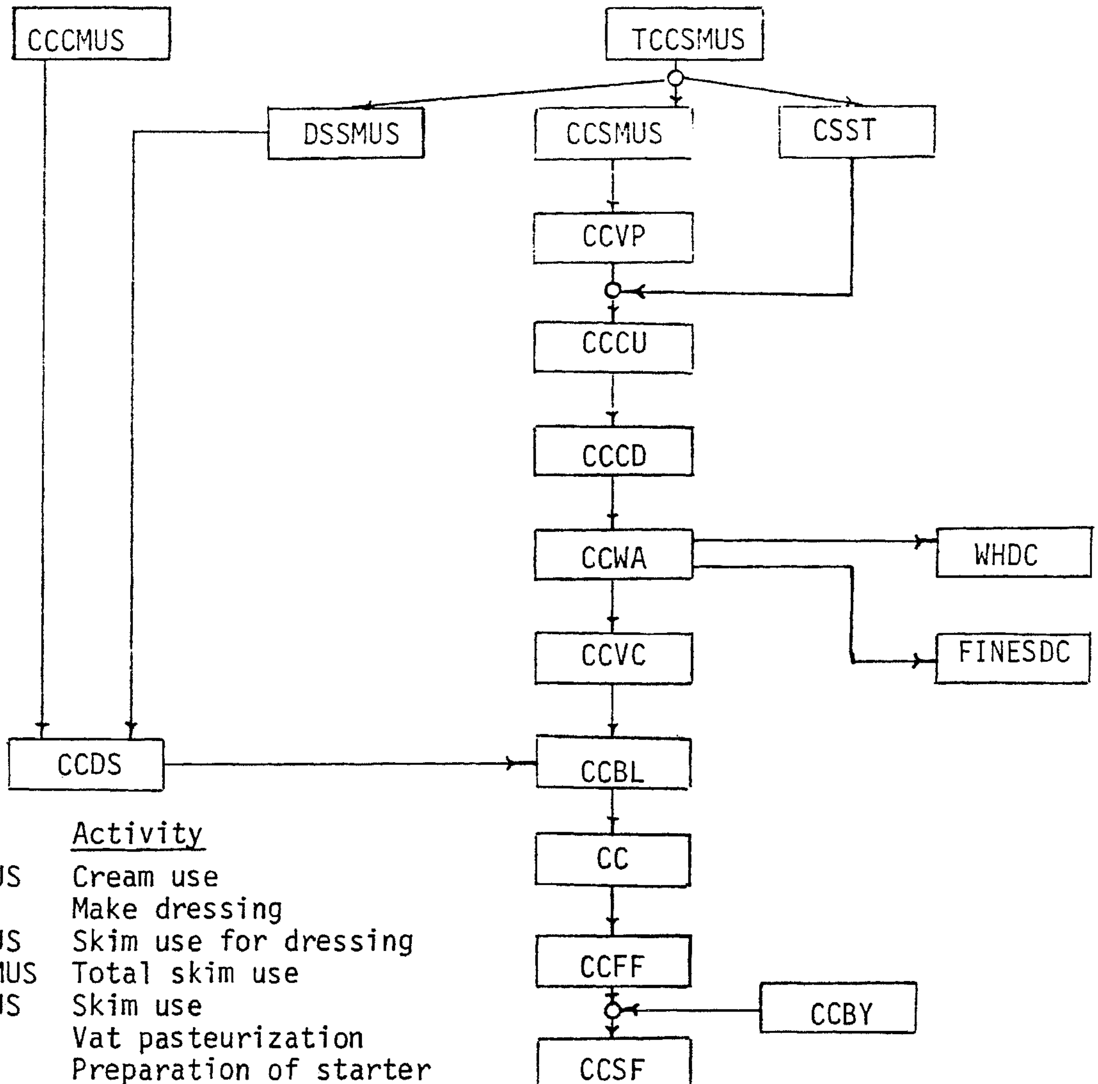
Sour Cream Processing. Sour cream also requires special process sequence as shown in Figure 7. The difference between buttermilk and sour cream processing is that a homogenization process is necessary to obtain the desired product quality. This step and the processing sequence was adapted from the material presented by Henderson (1971). The process sequence (Figure 7) begins with the blending (SCBL) of cream (SCCMUS), skimmilk (SCSMUS), condensed skim (SCCSUS) and stabilizer at 0.25% (SCSBUS) followed by vat pasteurization (SCVP) at 165 F for 30 min, homogenization at 3000 psi (SCHO), vat cooling to 72 F (SCVC), addition of 1% starter ripening of the mixture at 72 F for 12 14 hr, transfer (SCTR) of the sour cream to filler for filling (SCFF) and subsequently to storage (SCSF).

Cottage Cheese Processing. The selected process sequence for cottage cheese (Figure 8) begins with skimmilk (CCSMUS) which is vat pasteurized (CCVP) at 145 F for 30 min. then cooled to 90F



Code	Activity
SCCMUS	Supply cream
SCSMUS	Supply skim milk
SCCSUS	Supply condensed skim
SCSBUS	Supply stabilizer
SCBL	Blend ingredient
SCVP	Vat pasteurize
SCHO	Homogenize
SCVC	Vat cool
SCCU	Culture
SCST	Prepare and supply starter
SCTR	Transfer of sour cream
SCFF	Filling of sour cream
SCSF	Refrigerated storage

Figure 7. Production processes for sour cream with computer code designations.



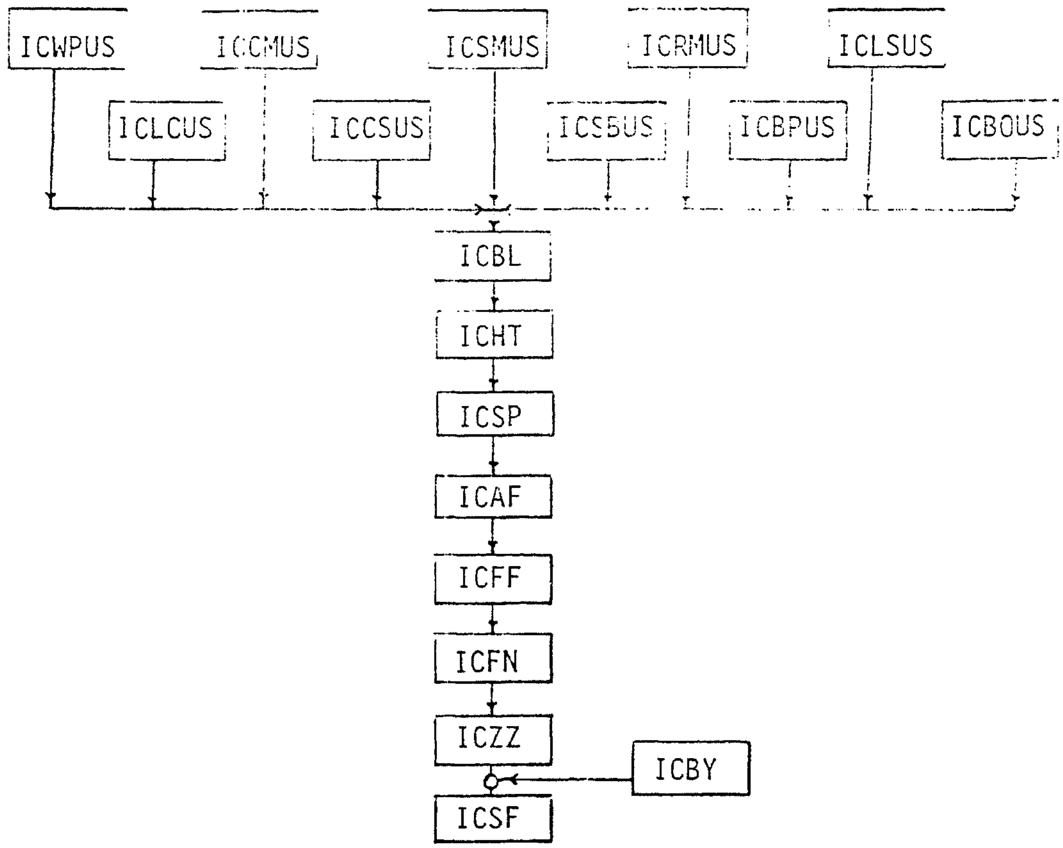
Code	Activity
CCCMUS	Cream use
CCDS	Make dressing
DSSMUS	Skim use for dressing
TCCSMUS	Total skim use
CCSMUS	Skim use
CCVP	Vat pasteurization
CSST	Preparation of starter
CCCU	Culture of skim and starter
CCCD	Curd
CCWA	Washing the curd
CCVC	Cooling the curd
CCBL	Mixing dressing and curd
CC	Creamed cottage cheese
CCFF	Filling cottage cheese
CCBY	Buying cartons of cottage cheese
CCSF	Storage of cottage cheese
WHDC	Whey discharge to sewer
FINESDC	Fines discharge to sewer

Figure 8 Process sequence for cottage cheese with computer code designations.

(CCVC) at which time rennet (1 ml/1000 lb) and starter (5%) are added as described by Henderson (1971) for the short set method. The milk is set (CCCU) for about 4 hr after which the curd is cut, and cooked by raising the water temperature about 1 F every 5 min till about 125 F (the cooking process takes 1-1.5 hr). After cooking, the whey is drained and the curd washed (CCWA), first with tempered water (about 85 F), followed by 60 F water and finally 45 F water. Following drainage of the wash water, the curd is mixed with dressing (CCBL) to make the finished creamed cottage cheese which is then packaged (CCFF) and finally stored in the cooler (CCSF). Cottage cheese can be bought packaged (CCBY). The whey (WHDC) and fines (FINESDC) are major pollution load factors and will be discussed in the process alternatives section.

Ice Cream Processing. The production processes for ice cream in the Case Study Plant are presented in Figure 9. The processes were selected to represent a high volume ice cream business with limited product mix.

The ice cream process sequence includes blending of ingredients (ICBL), pasteurization of the mix (ICHT), storage of the pasteurized mix, at which time flavors may be added (ICSP), freezing of the mix in continuous freezers (ICAF), followed by packaging of the frozen (semi-frozen) mix (ICFF) hardening of the ice cream (ICZZ) and then storage of the frozen ice cream (ICSF). As with fluid milk, and cottage cheese, ice cream can be bought (ICBY) packaged to satisfy the sales demand.



Code	Activity
ICBL	Blend ingredients
ICHT	Pasteurize (HTST)
ICSP	Pasteurized storage, aging
ICAF	Counter freezers
ICFF	Filling
ICFN	Feeding for fruit and nuts
ICZZ	Freezing in package
ICSF	Frozen storage
IC--US	Supply ingredients - WP, whey powder; CM, cream; SM, skim milk; RM, raw milk; LS, liquid sugar; LC, liquid corn syrup; CS, condensed skim; SB, stabilizer; BP, buttermilk powder; and BO, butteroil

Figure 9. Production processes for ice cream with computer code designations.

Process Alternatives

Selection of Process Alternatives

A number of process alternatives were considered during the course of this investigation. The process changes evaluated included a number suggested in reviews in the literature. Also, the authors personally received many ideas for process changes during plant visits and telephone conversations with dairy plant employees and management, dairy consultants and equipment designers and manufacturers.

A limited number of the potential process alternatives were selected for study. Reasons the changes were selected included: they were either commercially available or could be easily fabricated, water and wastewater coefficients could be reasonably estimated, costs of installation and operation could be estimated they were suitable for incorporation in the Case Study Plant.

Evaluation of Process Alternatives

The process alternatives selected for the reduction of water use or the reduction of waste load in the Case Study Plant were evaluated by two methods. All of the process alternatives were evaluated by the method used by Carawan *et al*. (1974) and Carawan (1977) for evaluating water and waste related changes. Most of the process alternatives also were evaluated in the linear analysis model.

The changes were evaluated by the Carawan *et al*. and Carawan (1977) method individually, in each of two categories: (a) water related changes and (b) waste related changes. Then the categories were combined for their composite effect on the Case

Study Plant.

The evaluation of the process alternatives proceeded as follows:

1. Each process alternative was individually evaluated and analyzed as follows:
   - (a) The justification for utilizing the process alternative was reviewed.
   - (b) A description of the change was made utilizing written notes and visual sketches when the authors felt a written description was not sufficient.
   - (c) Development of initial costs estimate for the process change and the predicted annual savings (costs) if the change were incorporated in the Case Study Plant. This development proceeded as follows:
     - (1) Estimate of the water use and waste load coefficients for the standard process as explained elsewhere in this section.
     - (2) Estimate of the reductions in water use waste load coefficients and the development of change coefficients.
     - (3) Estimate of the expenses involved in the installation and operation of the process alternative.
     - (4) Development of Initial Costs budget.
     - (5) Development of an Annual Budget summary.

The above information has been presented in detail by Carawan (1977).

2. After each process alternative was individually analyzed, category analysis was performed for the effect of the incorporation of the collective changes on plant operation, costs, water use and waste load. The category analysis proceeded as follows:

   (a) A list was made of the individual changes.

   (b) A summary was made of the individual changes including:

      (1) Water use reduction

      (2) BOD reduction

      (3) Initial costs

      (4) Annual savings (costs)

   (c) Ratios were developed to rank individual changes show a relative value for the change including:

      (1) Annual savings/annual costs

      (2) Annual savings/initial costs

      (3) Initial cost/water reduction

      (4) Initial cost/waste reduction

3. Next, a summary of the effect of the Case Study Plant of the incorporation of all the changes was prepared. The combined analysis of the net effect of all the process alternatives on the operation of the Case Study Plant proceeded as follows:

   (a) Water use reductions were summarized.

   (b) Waste (BOD) reductions were summarized.

   (c) Annual costs were totaled.

(d) Initial costs were totaled.

(e) Annual savings were totaled.

(f) The information was presented in a suitable format.

Initial cost and Annual Budgets

The value of a process alternative to a dairy processing plant such as the Case Study Plant can take several forms. Foremost, the value of any process or equipment change can be evaluated by management in terms of the return on investmant for the specific change. However, in the event of restrictions on water use or waste discharge, a change must be evaluated not only in terms of return on investment but in terms of the total value to the plant of that individual change. The linear analysis model was developed to help dairy plant management with the evaluation of the total value of process alternatives. However, costs are vital to the development of the data needed for the linear analysis model. Therefore, the calculation of initial costs and annual budgets was included in this study.

Initial cost budgets and annual budgets were developed similar to the methods used by Carawan et al. (1974) with the following exceptions as developed by Carawan (1977).

1. The Case Study Dairy Plant was analyzed instead of an operating poultry processing plant.
2. The costs and details of the develcpment differ in some respects. Specific costs, depreciation schedules and values as used are given.
3. Product loss prevention is valued.

4. Product recovery for ingredient use is permitted.

None of the exceptions change the validity of the method and most reflect the differences between poultry and dairy processing and the update of costs to reflect the dairy industry in 1976.

Initial Costs. Initial cost budgets or partial budgets include the costs of acquisition, installation and start-up of each process alternative as explained by Carawan (1977). These budgets for the equipment or process modifications or replacement do not reflect equipment already in place, but only those costs affected by the change. The costs would also exclude development costs that might be necessary or desirable for operating plant installation. Initial cost budgets were developed using the information in Table 13 and the format as shown in Table 14.

Annual Budget. Annual increased costs (ANNC) or annual increased savings (ANNS) are reflected in annual budgets. The annual budgets were developed for each process alternative using the information shown in Table 15 with the format as shown in Table 16. In some cases, the annual budget reflected the summation of several initial cost budgets when more than one of an item was needed and was so indicated on the annual budget.

Management Reduction Practices

Management control of water using and waste producing activities has been reported as essential to water and waste control in dairy processing (Zall, 1968; Zall and Jordan, 1973; Harper *et al*. (1971) and Carawan *et al*. (1972). These authors

Table 13. Formulas for Initial Cost Budgets.

Note	Description and Detail
1.	Installation labor (INSTL) charged at $13.00/hr (INSTLR) unless otherwise noted.
2.	Tax (TAX) charged at a tax rate (TAXR) of 2 percent of materials cost (MATLC).
3.	Initial costs (INITIAL) were equal to the material cost (MATLC), the tax (TAX)and the installation cost (INSTC).
4.	Installation costs (INSTC) include installation labor (INSTL), shipping costs (SHIPC) and other costs (INSOR).

Table 14. Format for the Development of Initial Costs.

ITEM	QUANTITY AND/OR RATE	AMOUNT[a]	TOTAL[a]
Material:		MATLC	\$ MATLC
Tax: @ 2% of MATLC			\$ TAX
Installation:			\$ INSTC
Labor @ \$13/hr -		INSTL	
Shipping		SHIPC	
Other (Erection, site preparation, welding, tool rental)		INSOR	
Total Costs:			\$ INITIAL

Table 15. Notes for Annual Budgets.

Note	Description and Detail
1.	Interest (INT) at an interest rate (INTR) of 9% charged on one-half of initial costs (INITIAL).
2.	Maintenance (MAINT) at 10% of material cost (MATLC) unless otherwise noted.
3.	Depreciation (DEPREC) on material cost (MATLC) at the following schedule:

Item	Depreciation (%)	Life (yrs)
Hoses, Nozzles	10	10
Motors, SS Tubing and SS Specialities	8.33	12
Equipment and Systems	6.67	15
Buildings	5.0	20

Note	Description and Detail
4.	Recurring labor (RECURL) and reduced labor (REDL) at $4.00/hour (LABR).
5.	Water and sewer rate at $0.30/1000 gal for water (BUYWAT) and $0.30/1000 gal for sewer (PAYSEW) or a total of $0.60/1000 (SWATER) for water and sewer unless specified.
6.	Surcharge (SURCHO costs and savings computed at $75/1000 lb BOD_5 (SURCHB) unless specified.
7.	All savings and costs computed using a 250 work day year, 5 day week with a 720 minute work day unless otherwise specified.
8.	Annual savings (ANNS) or costs (ANNC) for changes consist of increased costs (INCC) less savings per year (SPY) which is the sum of reduced costs (REDC) and increased revenue (INCR).
9.	Product loss prevention (LOSS) is computed at $0.02/pound of milk, $0.05/pound of ice cream and $0.15/pound of cottage cheese which represents only the value of processing the products.
10.	Product recovery is computed using a value of $0.05/pound for milk-solids-not-fat (MSNF) from "high solids" recovered product and $0.80/pound for butterfat (BF). Fines from cottage cheese processing recovered for use in product are valued at $0.90/pound.
11.	Electricity (ELEC) is charged at a rate of $0.0172/kwh. (Assuming 1 HP-hr = 1 kwh.
12.	Animal feed (ANIMF) valued at $0.01 per pound.
13.	Added CIP cycles for cleaning and sanitizing include the following: a) 700 gal water b) Chemical (Detergent Cost - $2.50/cycle) c) Neglect BOD_5 d) Heating water - 125 kw ($2.00) e) RECURL - 0.25 hrs ($1.00)
14.	Trucking (TRUCK) of materials such as whey collected for disposal costs $0.10/gal including the costs of disposal.

Table 16. Annual Budget for Change (CODE[c]).

ITEM	QUANTITY AND/OR RATE	AMOUNT[c]	TOTAL[c]
Reduced Costs:			$ REDC
Water Use @ $.30/1000 gal[d]		BUYWAT	
Water Use @ $.60/1000 gal (includes sewer)		SWATER	
Sewer Discharge @ $.30/1000 gal[a]		PAYSEW	
Surcharge @ $75/1000 lb BOD_5		SURCHB	
Loss Prevention	Milk @ .02/lb Ice Cream @ .05/lb Cottage cheese @ .15/lb	LOSS	
Increased Revenue			$ INCR
Ingredients - BF @ .80/lb		BF	
MSNF @ .05/lb		MSNF	
Animal Feed - @ .01/lb		ANIMF	
Fines - @ .90/lb		FINES	
Total Savings Per Year			$ SPY
Increased Costs:			$INCC
Labor @ $4/hr		RECURL	
Maintenance 10% of Material Cost		MAINT	
Depreciation - Hoses, Nozzles 10.00% of Material Cost, Motors, Piping, Other 8.33%, Equipment, Tanks and Systems 6.67%, Buildings 5.00%		DEPREC	
Interest 0.5 Initial Cost (9%)		INT	
Electricity @ $.0172/kwh		ELEC	
CIP Cycle @ 125 kwh (one/day = 31,250 kwh annually)			
Chemicals @ $.250/cycle (one/day = $625 annually)		CHEM	
Water		BUYWAT	
CIP Cycle = 700 gal (one/day = 175,000 gal x .60/1000 = $105. annually)			
Trucking - @ $0.10/gal		TRUCK	
Annual Savings Per Year:[b]			$ ANNS

[a]Use only when water use not involved

[b]Year = 250 days, 5 day/week, 720 minute/day

[c]Computer Codes

[d]Use only when sewer discharge not involved

agreed with the 50% reduction in water and waste reductions in the dairy industry and this value was used to predict the costs of management control of water and waste related activities and to predict the annual savings that could occur for the Case Study Plant. The authors realize that the procedure used was entirely subjective. However, the reductions shown are based on literature information, plant operating data and the authors' personal experiences in reviewing the water and waste situation in dairy plants through personal visits and discussions with dairy industry workers and management.

Process Alternatives for Water Reduction

Water Related Process Alternatives

Process alternatives for decreasing water utilization in the case study plant were evaluated individually and collectively and have been reported by Carawan (1977). A number of the changes utilized devices or systems to reduce the constant demand of water irrespective of production by many water using operations or equipment systems.

Process Alternatives for Waste Reduction

Waste Related Process Alternatives

A comparative analysis of the benefits and costs associated with each waste related process alternative was made and was reported by Carawan (1977). In addition to the individual evaluation of each process alternative selected for study, an overall analysis was made of the summation of the individual process changes to determine the net effects on water utilization, waste load and plant operating costs. The process alternatives selected have generally been proven in one or more dairy plant operations. The waste related process alternatives included the collection of various product and product-water mixtures.

Dairy Processing as a Linear Analysis Model

The development of the information needed for a linear analysis of the Case Study Dairy Plant was one of the objectives of this study. Information needed for linear programming studies include a definition of activities, coefficients of inputs and outputs for these activities, prices for the objective function and the restraints or restrictions dictated by the processes selected or assumed to affect the model.

The primary objective of the linear analysis model was to minimize the water and wastewater related costs and raw product costs for producing a predetermined amount of dairy products. The model was formulated to select from a number of alternative processes the least-cost set of raw materials input, water use, wastewater discharge and process alternatives that satisfy the given problem definition of providing a supply of dairy products to meet a sales demand. Problem definition is achieved by determination of the basic set of operations (activities) necessary to produce the products desired plus a full range of alternative operations including the possibility of buying needed products as well as selling excess production. From this inventory of alternatives, a least cost or "optimal" set of processes is selected which satisfies all resources limitations pertinent to the problem.

The authors followed the general optimization procedures as outlined by Beveridge and Schechter (1970). External restrictions examined included the supply of milk, supply of water and primarily restrictions that might be imposed by a municipality in trying to regulate its industrial sewer discharges. The system chosen for the study is the Case Study Dairy previously described in this section. The interrelationship of the system elements and the structure of the system (Case Study Dairy) were determined. A linear analysis model was constructed and the linear programming analysis method was chosen. Internal restrictions necessary to the Case Study Plant were identified and tabulated and consisted of things such as product composition, product formulation, etc. The objective function was identified to include those activities relating to water and waste including buying water (BUYWAT), paying for sewer discharge (SANSEWER), paying BOD^ surcharge (SURCHB), the activities involved with product losses and the activities supplying raw products. The model was analyzed and verified for the Case Study Plant. Sensitivity analyses were not performed to find the best cost coefficients for the model.

Formulation of Linear Programming Model

Problem definition was achieved through the specification and determination of the basic set of operations including the possibility of buying needed products as well as selling excess production.

Once an optimal solution was achieved, the next step was to note the specific changes in the solution set resulting from variations in the availability of resources. Resources, in the sense used here, include residual waste heat, recovered product streams, polluted process wastewater streams, as well as items normally viewed as resources such as raw materials, electricity and water. Using Linear Programming, these resource limitations may be implemented - (1) through variations in the cost of water withdrawal, (2) by placing discharge restrictions on specific pollutants such as BOD , FOG, (3) through variations in the price of surcharges and (5) by limiting the use of product recovery streams or waste treatment processes. Also, resources may be controlled by changing product quality or through price manipulation.

Linear Programming (LP), as used in this study, was a tool for optimally evaluating the process substitution possibilities of the Case Study Plant. A more detailed description of the model is included in Carawan (1977).

Model Development

Model development proceeded as had been recommended by Thompson *et al.* and as is shown in Table 17. The model design was considered to be representative of a modern, medium-sized multiproduct dairy plant.

"Once-through" cooling for condensing refrigeration vapors has probably already been eliminated from the feasible alternatives in a dairy plant because of costs and regulations.

Table 17. Method of Model Development.[a]

Step	Description
1.	Engineering flowgraphs of the production process and auxiliary processes were developed including raw material inputs, energy, water use, wastewater use, wastewater product waste, and waste treatment or disposal.
2.	Substituting processes were identified from the flow graphs.
3.	For each substituting process, quantities of inputs and outputs were quantified, coefficients developed and organized into an array of numbers called a tableau and costs of different operating efficiencies of major units calibrated using non-linear engineering submodels.
4.	Substitution possibilities are limited by phsyical laws governing production and other processes wastewater discharge restrictions and required levels of output.
5.	Cost-minimizing solutions to the linear model are calculated for each specification of effluent restrictions, water price, surcharge and differing raw materials.
6.	Each least-cost combination of processes gives a unique solution (inputs, outputs, cost, etc.). Incremental costs schedules are estimated and demand schedules developed.

[a]Thompson <u>et al</u>., 1976

However, the once-through cooling was instituted as an activity to give the model an initial basis. This basis was used to compare the effects of increasing costs and restrictions. To form this basis, an optimal solution is formed assuming that (1) water is free except for pumping cost (2) there is an unlimited supply of water and (3) the wastewater streams can be disposed of at no cost with no restrictions.

The authors assumed in each case that water is available either from wells or from a municipal supply. To provide the necessary water quality for product dilution and boiler fuel, the water may need to be dimineralized (MIF, 1967). For washing of cottage cheese, chlorination of the water is necessary to prevent contamination of the curd (MIF, 1967). These activities were not included in the model.

The premise of process alternatives to recover or reuse concentrated or diluted product streams is paramount to this model. The multiproduct design at the dairy plant gives products which can accept these recovered materials even under current regulations. Ice cream processing was designed to be the alternative receptor of these recovered materials other than disposing of them to the sewer.

Linear Programming Point

A number of steps were found necessary to develop the linear analysis model of the Case Study Plant in a suitable Linear Programming format. The steps were chosen from those listed by Callaway *et al*. (1974) as shown in Table 18. The steps included in this investigation were the following:

Table 18. Modeling Into Linear Programming Format.[a]

Step	Description
1.	Established Flow Diagrams.
	a. Show basic system components.
	b. Identify process alternatives.
	c. Indicate linkages and interrelationships.
2.	Quantify System Components and decide on sign convention.
	a. Inputs (-)
	b. Outputs (+)
3.	Fit Components Into LP Structure
	a. Component = Column "Activities"
	b. Input = Row "Resources"
	c. Output = Row "Resources"
	d. Limitations = Row "Restrictions"
	e. Matrix = Tableau "Technology Matrix"

[a]Callaway *et al.*, 1974

1. Data input format was selected.
2. Activities were coded for the development of the linear analysis model.
3. Flow diagrams were developed:
    (a) Activities were identified.
    (b) Alternate processes were identified alternate activities.
    (c) The raw product-final product linkages and interrelationships were identified.
    (d) The water-waste linkages and interrelationships were identified for every activity.
4. The system was quantified:
    (a) costs were estimated for the objective function.
    (b) Sign convention was adopted.
    (c) Input-output coefficients were developed for each activity emphasizing those inputs and outputs that were water or waste related.
    (d) Internal and external restrictions were established for the Case Study Plant.
    (e) Cost coefficients for the process alternatives were generated.
5. A card deck was generated.
6. An evaluation(s) of the linear model was made to verify the model.
7. Evaluations of the model were generated to study the effect of changes in objective function costs and policy limitations restricting wastewater discharge.

Dairy Plant Parameters

A number of dairy plant parameters were needed for this investigation. These included costs of products, production, labor, water, sewer discharge; water, wastewater and waste load coefficients; internal restrictions for the Case Study Plant such as machine limitations and product formulations: external restrictions for the Case Study Plant such as raw milk supply, water supply and sewer disposal limits; information about daily operations expected for the Case Study Plant such as lubrication usage, chemical and cleaner usage for CIP operation and the costs and effects on process of the process alternatives selected for evaluation. The parameters were obtained directly or derived from information supplied by one of the following sources:

(1) Harper _et al_., 1971

(2) EPA, 1974

(3) Carawan _et al_, 1974

(4) Literature review

(5) Personal contact with the dairy industry

References are provided for data which can be attributable to a single source. However, in most cases, the authors had to manipulate and extend the data to such a degree that it will be presented as original data developed for this investigation.

Waste, Water and Wastewater Coefficients

Waste loads are frequently expressed in terms of the concentration of some wastewater parameter such as BOD. Concentrations are frequently expressed as parts per million (ppm) or milligrams per liter (mg/l). Although the concentration can be a significant parameter, the definition of a waste load requires a given amount of a constituent. In addition to concentration, the volume of wastewater must be given to arrive at a waste load. The following equation was used:

$$\text{Waste Load} = \frac{(8.34)\ (\text{VOLUME})\ (\text{CONCENTRATION})}{1{,}000{,}000}$$

where:	Waste Load	(lb)
	Volume	(gal)
	Concentration	(mg/l, ppm)

Much of the data obtained from the literature and personal contacts was in a format or units inconsistent with those of this investigation. Therefore, water, wastewater and waste loads data were converted where necessary utilizing the format developed by Carawan (1977). The conversions shown were developed by these authors with information obtained from other sources (Table 19). Primarily, the milk equivalent concept as used utilizes the procedure given by Harper et al., 1971 in that 6.25 lb milk is equivalent to 1 lb cottage cheese and that 2.7 lb milk is equivalent to 1 lb ice cream. The problems of utilizing the milk equivalent concept were discussed previously.

Much of the data concerning water use, wastewater discharge and waste loads from the dairy industry was found to be presented with the coefficient expressed per unit of milk received, or processed, or on a milk equivalent basis. For the purpose of this investigation, the authors assumed that these three quantities are numerically equal for fluid milk processing.

Table 19. Conversions for Common Water Use, Wastewater and Waste Load Data.

Product	Original Units	Conversion Factor	Final Units
	Wastewater - Water Use		
Milk (FM)	lb water/lb milk[a]	x 120[b]	gal/1000 lb product
	gal water/1000 lb milk	x 1	
Cottage Cheese (CC)	lb water/lb milk	x 749[c]	gal/1000 lb product
	gal water/1000 lb milk	x 6.25	
Ice Cream (IC)	lb water/lb milk	x 324[d]	gal/1000 lb product
	gal water/1000 lb milk	x 2.7	
FM, CC, IC	lb water/lb milk	x 204[e]	gal/1000 lb product
	gal water/1000 lb milk	x 1.7	
	Waste Load		
Milk (FM	lb waste/lb milk	x 1000	lb/1000 lb product
	lb waste/1000 lb milk	x 1	
Cottage Cheese (CC)	lb waste/lb milk	x 6,250[f]	lb/1000 lb product
	lb waste/1000 lb milk	x 6.25	
Ice Cream (IC)	lb waste/lb milk	x 2,700[g]	lb/1000 lb product
	lb waste/100 lb milk	x 2.7	
FM, CC, IC	lb waste/lb milk	x 1,700[h]	lb/1000 lb product
	lb waste/1000 lb milk	x 1.7	

[a]Milk = milk processed approximately equal to milk receipts approximately equal to milk equivalents.

[b]1000 lb ÷ 8.34 lb wastewater/gal wastewater

[c]1000 lb x 6.25 lb milk/lb cottage cheese ÷ 8.34 lb wastewater/gal wastewater

[d]1000 lb x 2.7 lb milk/lb ice cream ÷ 8.34 lb wastewater/gal wastewater

[e]1000 lb x 1.7 lb milk/lb product ÷ 8.34 lb wastewater/gal wastewater

[f]6.25 lb milk/lb cottage cheese x 1000 lb

[g]2.7 lb milk/lb ice cream x 1000 lb

[h]1.7 lb milk/lb product x 1000 lb

Units desired for wastewater were gal wastewater/1000 lb product where product might be either fluid milk (FM), cottage cheese (CC), ice cream (IC) or total products (TP). The conversion factor for milk to convert from lb water/lb milk (processed, received or ME) to gal/1000 lb milk products was calculated to be 120 which was determined by unit conversion equal to 1000 lb product divided by 8.34 lb water/gal water. It was assumed that 1 lb milk received at the plant equaled 1 lb of milk products which is not necessarily true. For instance, product lost in processing is not reflected in this assumption. However, added ingredients were included in the calculations. Thus, the authors feel that this assumption is reasonably accurate for the use intended.

The wastewater conversions (Table 19) presented for cottage cheese reflect the milk equivalent conversion factor of 6.25 lb milk/lb product. To convert lb water/lb milk, a conversion factor of 749 was developed. To convert gal water/1000 lb milk, a conversion factor of 6.25 was used.

The wastewater conversions for ice cream reflect the milk equivalent conversion factor for ice cream of 2.7 lb milk/lb ice cream. Factors developed were 324 for lb water/lb milk and 2.7 for gal water/1000 lb milk.

Since the dairy plant was a multiproduct plant, another assumption was required related to the milk equivalent factor for a mixed product facility. It was assumed that the total products were 80% fluid milk, 10% ice cream and 10% cottage cheese. The milk equivalent factor developed using this assumption was 1.7 lb milk/lb product which was based on the appropriate ME factors for ice cream and cottage cheese. The wastewater conversion factors developed were 204 for lb water/lb milk and 1.7 gal water/1000 lb milk.

Waste load conversion factors were developed similarly. The units desired were lb waste/1000 lb product where the product would be either fluid milk (FM), ice cream (IC), cottage cheese (CC) or total products (TP). The conversion factors developed were 1000 for lb waste/lb milk to lb waste/1000 lb products. Cottage cheese conversion factors were 6,250 for lb waste/lb milk and 6.25 for lb waste/100 lb milk. Ice cream conversion factors developed included 2700 for lb waste/lb milk and 2.7 for lb waste/1000 lb milk. The multiproduct plant conversion factors were 1700 for lb waste/lb milk and 1.7 for lb waste/1000 lb milk.

The data of Harper _et al_. (1971) which was used extensively in the development of the waste coefficients did not include drips, leaks, spills, and/or bad batches of product all of which contribute to product loss and waste load coefficients and often did not adequately reflect on the nature of the product. For these reasons and the need to determine product loss coefficients, the relationship of product, product loss and waste coefficient was developed.

Relationship of Product, Product Loss and Waste Coefficient

Harper _et al_. (1971) presented how viscosity, product loss and BOD are related for dairy products. Carawan (1977) utilized this information to the concept of the BOD HFACTOR and the BOD RATIO HFACTOR. These were used to help estimate the product loss and waste coefficients.

Linear Analysis Inputs

Because of the numerous details necessary to explain the development of the linear analysis inputs such as costs, restrictions and activity coefficients; the details for the development of each input will be explained as the inputs are developed in the results section. This should enable the reader to more readily comprehend the procedure and will shorten the text.

RESULTS AND DISCUSSION

The Case Study Plant

Values for water use, wastewater, waste load (BOD), product loss and fat loss coefficients were known to be needed for the Case Study Plant. First a Benchmark or initial estimate of the gross wastewater and waste load characteristics was made by the authors. Then an arbitrary 50% reduction in wastewater and waste load from the Benchmark Characteristics was assumed to develop gross wastewater and waste load (BOD characteristics) for Management Action Coefficients. Then the Management Action Coefficients were used to guide the authors in the development of coefficients for each individual process known or believed to contribute to the water and waste parameters.

Benchmark Coefficients

The wastewater and waste coefficients for the Benchmark or initial estimation for the Case Study Plant are shown in Table 20 as developed by Carawan (1977). These coefficients represents arbitrary estimates for the overall product categories, namely fluid milk (FM), cottage cheese (CC) and ice cream (IC).

The Benchmark wastewater coefficient assumed for the Case Study Plant was 400 gal/1000 lb fluid milk products (FM), 1,100 gal/1000 lb ice cream (IC), 4,500 gal/1000 lb cottage cheese (CC) and 100 gal/1000 lb drinks (DR). The total products (TP) wastewater coefficient was 490 gal/1000 lb total products and is only 10% greater than the calculated industry mean of 446 gal/1000 lb total product (Carawan, 1977).

Table 20. Benchmark Coefficients for Case Study Plant.

Product	(Code)	Annual Production	Wastewater Coefficient Wastewater/Product	Waste Coefficient BOD_5/Product
		(1000 lb)	(gal/1000 lb)	(lb/1000 lb)
Fluid Milk	(FM)	95,000	400	6
Ice Cream	(IC)	5,000	1,100	24
Cottage Cheese	(CC)	1,500	4,500	225
Drinks	(DR)	2,750	100	2
Total Products	(TP)	104,250	490	10

The waste coefficients assumed for the Benchmark for the Case Study Plant were 6 lb BOD/1000 lb fluid products (FP), 24 lb BOD/1000 lb ice cream (IC), 225 lb BOD/1000 lb cottage cheese (CC) and 2 lb BOD/1000 lb drinks (DR). The total products (TP) waste coefficient was found by the summation of the annual products production and the respective waste coefficients divided by the annual total products production. The waste coefficient found was 10 lb BOD/1000 lb total products (TP). This value was approximately 20% larger than the total products industry mean (Carawan, 1977).

Management Action Coefficients

The role of management in controlling the water use, wastewater discharge and wastes has been thoroughly reviewed. However, in the authors' opinion the actual value or importance of managements role has not been sufficiently demonstrated. Therefore, a special category of water and waste characteristics was incorporated into this study to help demonstrate the value of management control of water and waste in dairy processing. This category is called Management Action Coefficients and these were tabulated in Table 21. The values presented equal the 50% reduction in wastewater and waste coefficients postulated as possible by Zall, 1968; Harper *et al.*, 1971; Harper, 1974; and EPA, 1974, and which the authors considered to be realistic. The 50% reduction was taken of the Benchmark Coefficients found in Table 20.

The Management Action (Table 21) wastewater coefficients estimated for the Case Study Plant were 200 gal/1000 lb fluid

Table 21. Management Action Coefficients for Case Study Plant.

Product	(Code)	Wastewater Coefficient[a] Wastewater/Product	Waste Coefficient[a] BOD_5 Product
		(gal/1000 lb)	(lb/1000 lb)
Fluid Milk	(FM)	200	3
Ice Cream	(IC)	550	12
Cottage Cheese	(CC)	2250	112
Drinks	(DR)	50	1
Total Products	(TP)	242	5

[a]Calculated on the basis of 50% reduction in Benchmark Coefficients

milk products (FM), 550 gal/1000 lb ice cream products (IC), 2250 gal/1000 lb cottage cheese (CC), 50 gal/1000 lb drinks (DR) and 242 gal/1000 lb total products (TP). The Management Action (Table 21) waste coefficients estimated for the Case Study Plant were 3 lb BOD/1000 lb fluid milk products (FM), 12 lb BOD/1000 ice cream (IC), 112 lb BOD/1000 lb cottage cheese (CC), 1 lb BOD/1000 lb of drinks (DR) and 5 lb BOD/1000 lb of total products (TP).

Fluid Milk Processing Coefficients

The coefficients for the significant water using and waste generating processes for fluid milk processing were largely derived by the authors utilizing the industry coefficients as explained by Carawan (1977). The individual process effluent BOD coefficients were reconciled to total 200 gal wastewater and 3 lb BOD/1000 lb fluid milk (Table 22) as to be consistent with the overall Management Action Coefficients (Table 21). The most significant water using activity was the HTST system using 110 of the 210 gal water/1000 lb of fluid milk. The significant water using activities are shown in Figure 10.

For the Case Study Plant, the effluent coefficient was predicted to be 200 gal/1000 lb fluid milk (FM) while the water use was predicted to be 210 gal/1000 lb fluid milk processed (Table 22). The total BOD coefficient was predicted to be 3 lb BOD/1000 lb fluid milk processed. Product loss was estimated to be 31 lb milk loss/1000 lb of fluid milk while the fat loss was estimated to be 1.02 lb fat loss/1000 lb of fluid milk processed.

Sour Cream and Buttermilk. Sour cream and buttermilk

Table 22. Coefficients for Fluid Milk Processing in Case Study Plant.

Process	Code	Water Use	Effluent	BOD_5	Product Loss	Fat Loss
		Fluid Milk Processed				
		(gal/1000 lb)	(gal/1000 lb)	(lb/1000 lb)	(lb/1000 lb)	(lb/1000 lb)
Receiving	RC	16	16	0.2	2	.07
Separation	PR	2	2	0.1	1	.03
Clarification	CL	2	2	0.1	1	.03
Raw Storage	RS	20	20	0.2	2	.07
HTST	HT	110	100	1.3	14	.45
Pasteurized Storage	SP	20	20	.2	2	.07
Filling	FF	10	10	.3	3	.10
Conveying	CV	1	1	.1	1	.03
Storage	SF	2	2	.1	1	.03
Returns	RT	12	12	.4	4	.14
Distribution	SH	5	5	-	-	-
Miscellaneous	-	10	10	-	-	-
Total		210	200	3.0	31	1.02

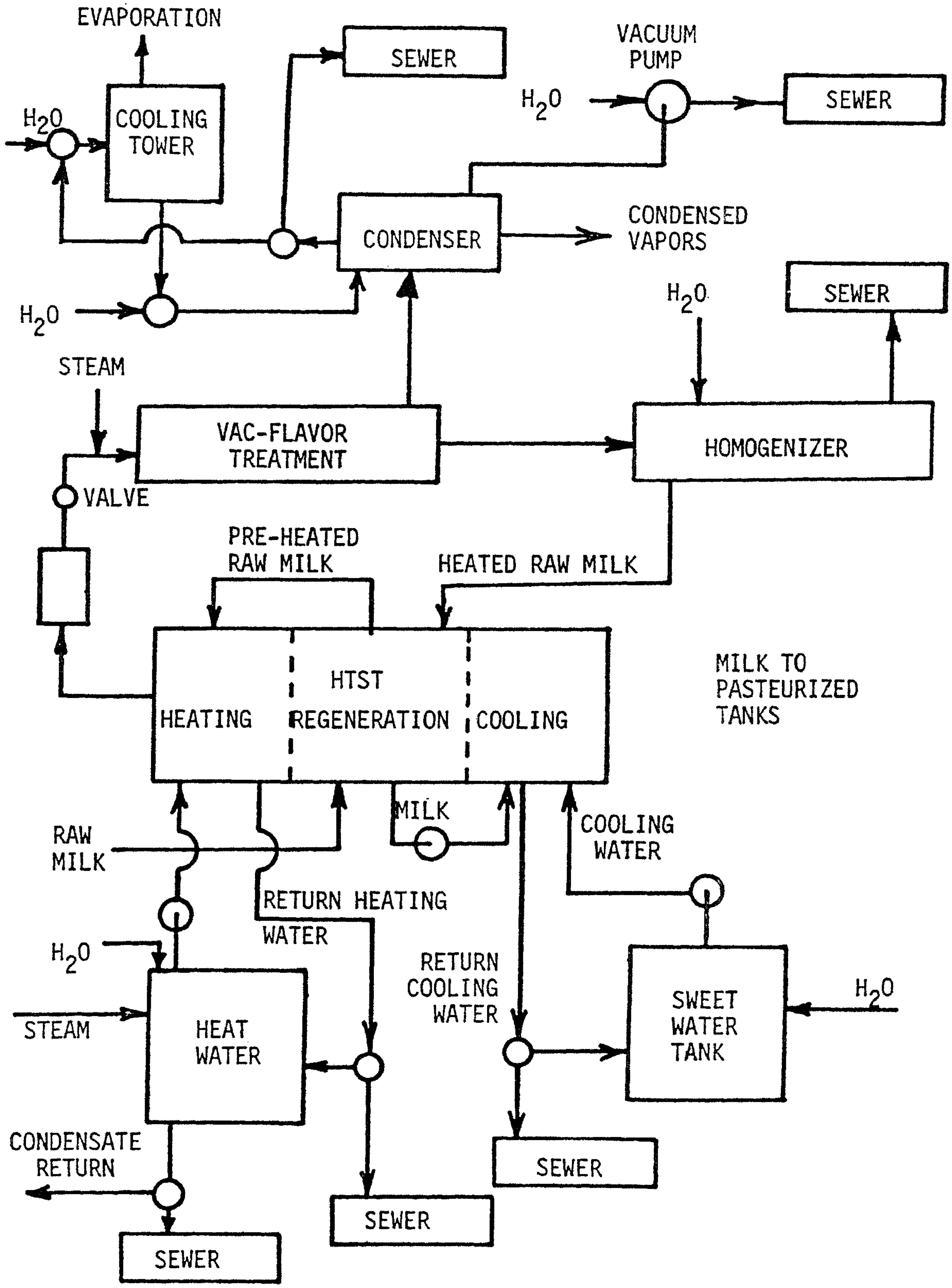


Figure 10. Water Using Activities Associated with HTST System.

processes differ from those of other fluid milk products. Both products are vat pasteurized and cultured as has been explained previously. Also, the product composition and viscosity differ significantly from the other fluid milk products. For these reasons, the procedure of Carawan (1977) using the HFACTOR and RATIO HFACTOR was utilized for these products.

The coefficients developed for buttermilk processing are shown in Table 23. Water use and wastewater coefficients were predicted to be 1485 gal/1000 lb buttermilk processed. The waste coefficient was estimated to be 3.66 lb BOD/1000 lb buttermilk. Product loss coefficient was estimated as 38 lb buttermilk/1000 lb buttermilk while the fat loss was estimated at 0.76 lb fat/1000 lb buttermilk.

The coefficients developed for sour cream processing for the Case Study Plant are tabulated in Table 23a. Water use and wastewater discharge were predicted at 1500 gal/1000 lb sour cream for each coefficient. The BOD coefficient was estimated as 18.74 lb BOD/1000 lb sour cream. Product loss was estimated to be 80.66 lb/1000 lb sour cream. Fat loss was estimated at 14.99 lb fat/1000 lb sour cream.

Cottage Cheese Processing Coefficients

Significant water using and waste generating processes for cottage cheese identified for the Case Study Plant are shown in Table 24 with their respective coefficients. Water use was predicted by the summation of the individual operation estimates to be 2431 ga/1000 lb cottage cheese (Table 24) which is more than the 2250 gal wastewater/1000 lb cottage cheese predicted for

Table 23a. Coefficients for Sour Cream Processing in Case Study Plant.

Process	Code	Water Use	Effluent[b]	BOD_5[b]	Product Loss	Fat Loss
		Sour Cream Processed				
		(gal/1000 lb)	(gal/1000 lb)	(lb/1000 lb)	(lb/1000 lb)	(lb/1000 lb)
Vat Pasteurization	SCVP	1200	1200	10.77	46.62	8.62
Vat Cooling	SCVC	120	120	-[a]	-[a]	-[a]
Homogenization	SCHO	15	15	.46	2.0	.37
Culturing	SCCU	120	120	-[a]	-[a]	-[a]
Store Pastuerized	SCSP	20	20	5.4	23.	4.32
Filling	SCFF	10	10	.71	3.0	.57
Conveying	SCCV	1	1	.23	.99	.18
Storage	SCSF	2	2	.23	.99	.18
Returns	SCRT	12	12	.94	4.1	.75
Total		1500	1500	18.74	80.66	14.99

[a]Assumed in SCVP

[b]Carawan, 1977

Table 23. Coefficients for Buttermilk Processing in Case Study Plant.

Process	Code	Water Use	Effluent	BOD_5	Product Loss	Fat Loss
		Buttermilk Processed				
		(gal/1000 lb)	(gal/1000 lb)	(lb/1000 lb)	(lb/1000 lb)	(lb/1000 lb)
Vat Pasteurization	BMVP	1200	1200	2.26	23.54	.47
Vat Cooling	BMVC	120	120	-	-	-
Culturing	BMCU	120	120	-	-	-
Pasteurized Storage	BMSP	20	20	.52	5.4	.11
Filling	BMFF	10	10	.39	3.0	.06
Conveying	BMCV	1	1	.10	1.	.02
Storage	BMSF	2	2	.10	1.	.02
Returns	BMRT	12	12	.39	4.1	.08
Total		1485	1485	3.66	38.00	0.76

Table 24. Coefficients for Cottage Cheese Processing in Case Study Plant.

Process	Code	Product	Water Use	Effluent	BOD_5	Product Loss	Fat Loss
					Product		
			(gal/1000 lb)	(gal/1000 lb)	(lb/1000 lb)	(lb/1000 lb)	(lb/1000 lb)
Skim Transfer	TCCSMUS	Skim	1.2	1.2	.08	1.	.0001
Cream Transfer	CCCMUS	Cream	15	15	.30	4.	.0004
HTST	CCHT	Skim Milk	18	16	.70	9.	.0009
Starter Preparation	CCST	Starter	12	12	.30	4.	.0004
Culture	CCCU	Skim Milk	24		14.17	191.	.019
Washing	CCWA	Curd	1500		9.	50	.15
Cooling	CCVC	Curd	370	370	0.6	3	.009
Blending	CCBL	Curd	75	75	2.0	10	.03
Filling	CCFF	Cottage Cheese	40	40	2.4	12	.036
Storage	CCSF	Cottage Cheese	2.5	2.5	0.4	2	.006
Distribution	CCSH	Cottage Cheese	5.0	5.0	0.2	1	.003
Dressing Preparation	CCDS	Dressing	2.0	2.0	.2	1	.003
Totals			2431[b]	3081[b]	112[b]	82[b,c]	NA

[a] Includes whey [b] Product for totals is cottage cheese [c] Whey excluded

the Case Study Plant by the authors in Table 21. Wastewater was shown to total 3081 gal wastewater/1000 lb cottage cheese which includes the whey discharge. The predicted wastewater coefficient (Table 21) and the total of the operations coefficients (Table 24) could not be resolved satisfactorily by the authors. The volume of the whey discharge is considered to be a major part of the difference. However, the approximately 40% variation, though large, will not significantly affect the total plant operation since cottage cheese processing is such a small proportion of total production. However, the effect on the Case Study Plant of the cottage cheese operation may be overemphasized if the processing total wastewater is less than the 3081 gal wastewater/1000 lb cottage cheese.

The waste load (BOD) found by the summation of the individual operation estimates (Table 24) was reconciled to be 112 lb BOD/1000 lb cottage cheese which had been the waste value predicted for cottage cheese in Table 21 for the Management Action Coefficients.

Product loss was estimated for the individual processes and totaled to be 82 lb cottage cheese loss/1000 lb cottage cheese.

Ice Cream Processing Coefficients

The estimated values of the Management Action Coefficients (Table 21) for the Case Study Plant for ice cream processing were used to help in the determination of individual process water and waste related coefficients. The Management Action Coefficients for ice cream were estimated to be 550 gal wastewater/1000 lb ice cream with a waste load (BOD) coefficient of 12 lb BOD/1000 lb ice cream. The process coefficient values estimated by Harper *et al*. (1971) were used as a basis for estimating the individual process coefficients. Process wastewater and BOD coefficients were reconciled to correspond to the Management Action Coefficients which were 550 gal water use, 550 gal wastewater and 12 lb BOD/1000 lb ice cream processed respectively. The coefficients for the significant water using and waste processes as estimated are shown in Table 25. Product loss was estimated at 60.1 lb/1000 lb ice cream. Fat loss summarized for the individual processes totaled 6.2 lb/1000 lb ice cream.

Ancillary Processes

The identification of processes not related to product productions is perhaps unique to this investigation and that of Carawan (1977). The authors found no sources of water and waste coefficients for non-product dairy plant processes. However, water use coefficients for a number of those processes were found in the study of Carawan *et al*. (1972). Others as presented were developed by the authors using the best information available (Table 26).

In the future, the complete utilization of ancillary process coefficients may require the modification of the product process coefficients which have been determined for the Case Study Plant in this study (Tables 23, 24 and 25). The authors have found no conclusive evidence in searching the literature wastewater and waste coefficients to find how or if the ancillary processes identified for the Case Study Plant were included in the coefficients found or estimated in the respective studies.

Table 25. Coefficients for Frozen Processing in the Case Study Plant.

Process	Code	Water Use	Wastewater	BOD_5	Product Loss	Fat Loss
		Ice Cream Processed				
		(gal/1000 lb)	(gal/1000 lb)	(lb/1000 lb)	(lb/1000 lb)	(lb/1000 lb)
Receiving	(RMRC)	40	40	.6	3.	.3
Storage	(RMST)	44	44	.6	3.	.3
Standardizing	(RMSP)	10	10	.3	1.5	.2
Blending	(ICBL)	28	28	.6	3.	.3
HTST	(ICHT)	160	160	4.0	20.	2.
Pasteurized Storage	(ICSP)	50	50	1.1	5.6	.56
Flavoring, Fruit and Nuts	(ICIN)	10	10	.3	1.5	.15
Freezing	(ICAF)	110	110	2.4	12.	1.2
Filling	(ICFF)	70	70	1.0	5.	.5
Conveying	(ICCV)	20	20	.2	1.	.1
Hardening	(ICZZ)	-	-	.3	1.5	.2
Storage	(ICSF)	3	3	.3	1.5	.2
Distribution	(ICSH)	5	5	.3	1.5	.2
Totals		550	550	12.0	60.1	6.2

Table 26. Estimated Coefficients for Plant Areas Other Than Process.

Process Area	Code	Water Use[d]	Effluent[a]	BOD_5	FOG[c]
		Total Products			
		(gal/1000 lb)	(gal/1000 lb)	(lb/1000 lb)	(lb/1000 lb)
Office	ADMINIS	2.4	2.4	0.005	.001
Garage	GARAGES	10.8	10.8	0.05	.025
Boilers	BOILERS	22.8	2.3[b]	-	-
			10.5	-	-
Cooling Tower	COOLTOWB	56.4	5.6	-	-
Shell-n-Tube	COOLTOWA	4320.	4320. [b]	-	-
Restrooms	LOCKERS	6.5	6.5	.01	.002
Case Repair	REFREP	1.2	1.2	.01	.005
Air Compressors	AIRCOMPA	39.	39. [b]	-	-
Sweet Water	SWEETA	24.	24.	-	-
Refrigeration Compressors	REFRIGEA	144.	144.	-	-

[a]Sanitary sewer system unless noted

[b]Storm sewer system

[c]FOG = Fats, oils and greases

[d]Based on field observations and data of Carawan et al., 1972

Cleaning coefficients were determined for the Case Study Plant based on an analysis of two existing dairies (Carawan, 1977) and information from suppliers of cleaning materials. Cleaning-in-place (CIP) systems for the Case Study Plant were assumed to be two basic units with one in the raw milk receiving area and one in the processed products areas. Estimations of water use, effluent and BOD load were developed by Carawan (1977). The single use, rinse recovery system was estimated to use less water than the reuse type system (Carawan, 1977). Lubrication coefficients were developed for the Case Study Dairy based on information developed by Carawan, 1977.

Coefficients for plant areas other than process (OTHER) were estimated based on data of Carawan _et al_. (1972) and Carawan (1977) and are listed in Table 26. Water use was estimated to be 2.4 gal/1000 lb total product for the office and sales area (ADMINIS) with an equal effluent stream. Water use for the garage area for truck maintenance and repair (GARAGES) was 10.8 gal/1000 lb total products with an equal effluent stream. Water use for the boilers was estimated at 22.8 gal/1000 lb total product while the effluent was estimated to be 2.3 gal/1000 gal total product discharged to the storm sewer for blowdowns and 10.5 gal/1000 lb total products returned to the sanitary sewer. Water use was estimated on the basis of field observations for two methods of condensing the refrigeration vapors. First, cooling using recirculation of water and cooling towers (COOLTOWB) was estimated to use 56.4 gal water/1000 lb total products and to have an effluent discharge of 5.6 gal wastewater/1000 lb total products. Second, cooling using shell and tube heat exchangers (COOLTOWA) was estimated to use 4320 gal/1000 lb total products with an equal effluents discharge. Restrooms (LOCKERS) were estimated at 6.5 gal/1000 lb total products. Refrigeration case repairs shop (REFREP) was estimated at 1.2 gal/1000 lb total products. The three air compressors (AIRCOMPA) were estimated to use 39 gal water/1000 lb total product which could be discharged to the storm sewer. The chilled water recirculating system (SWEETA) was estimated to use 24 gal water/1000 lb total products with an equal effluents discharge. The cooling water for the heads of the refrigeration compressors (REFRIGEA) was estimated at 144 gal/1000 lb total products with an equal effluent discharge.

Benchmark

A Benchmark or initial starting point for evaluating water and waste related changes was developed for the Case Study Plant. Selected results are shown in Figure 11. Total wastewater flow was estimated at 59,525,000 gal/yr with a BOD load of 1,033,000 lbs BOD/yr. The Benchmark was established using the Benchmark characteristics in Table 20.

Water Use

Industry contact by Carawan (1977) established a range of approximately 60 to 90% of water use being equal to the wastewater flow for typical dairies. Assuming 70% of water use to be wastewater, the water use was 1.43 times the wastewater discharge. On this basis, the author estimated water use would

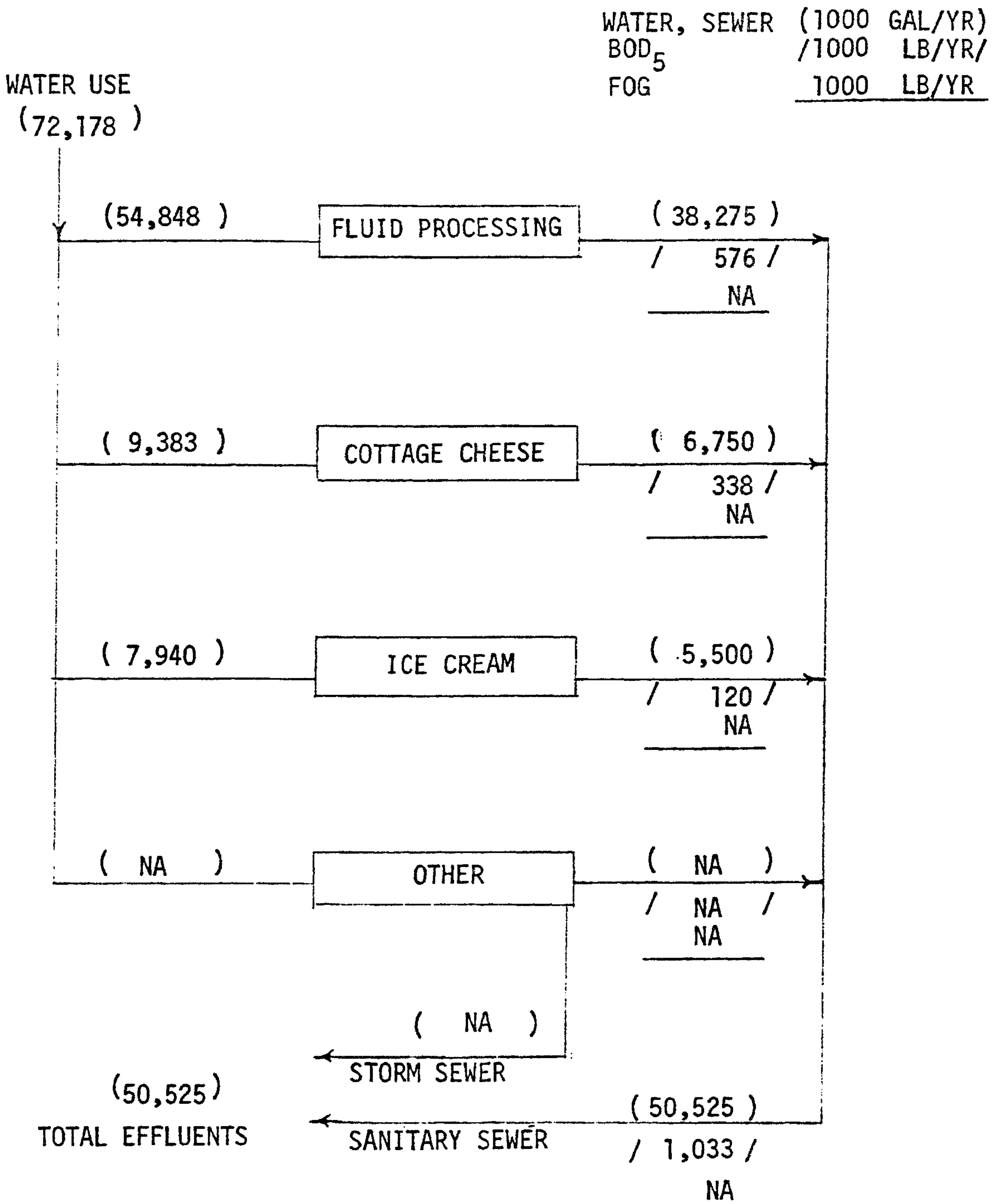


Figure 11. Benchmark Water Use and Effluents Discharge.

be 72,178,000 gal/yr. Flows to the product processing areas were assumed to be 1.43 times the wastewater discharge for each product.

Effluents

Total effluents from the Case Study Plant were estimated to be 50,525,000 gal wastewater/yr (Figure 11) which equals to 202,100 gal/day. Fluid products processing was estimated to contribute 76% or 38,275,000 gal/yr. Cottage cheese processing was 13% or 6,750,000 gal/yr. No overall estimates were made for plant areas other than process.

Wastewater Characteristics

The weighted BOD concentration for the Case Study Plant would be 2451 mg/l for the wastewater flow and waste load (BOD) as calculated from the data given in Figure 11. The BOD concentrations for fluid milk processing was calculated to be 1800 mg/l BOD. Ice cream processing calculated to be 2616 mg/l BOD. Cottage cheese processing was 5995 mg/l BOD. Drinks processing effluent was 2398 mg/l BOD. The authors found that these concentrations were generally within the expected values except that ice cream is too large or that the waste load is too small for the concentration expected from ice cream based on field observations would be greater than 2616 mg/l BOD. Of course, any change in the ice cream coefficients would effect the final wastewater characteristics. However, the authors do not believe that a change in the coefficients can be reasonably justified at this time in that a consistent seemingly reasonable procedure was followed in developing the coefficients for each process area and no better data were available.

Waste Load

The total waste load estimated for the Case Study Plant was 1,033,000 lb BOD/yr or 4132 lb/day. The fluid products processing area was estimated to contribute 56% of the waste load, or 576,000 lb/yr (Figure 11). Cottage cheese processing was estimated to contribute 33% of the waste load, or 338,000 lbs BOD/yr. Ice cream processing was estimated to contribute the remaining 11% of the load, or 120,000 lb BOD/yr.

Operating Characteristics

The Case Study Plant Benchmark was established using the minimum production figures specified for the plant. Production was 104,250,000 lb total products/yr or a daily production of 417,000 lb total products/day. The processing of products was assumed to be on a 250 work-day year. Annual production was 95,000,000 lb fluid milk, 5,000,000 lb ice cream, 1,500,000 lb cottage cheese and 2,750,000 lb drinks.

Monthly Water and Waste Related Costs

Monthly costs of water and waste related costs were found to be approximately $80,000/mo. These costs included water, sewer, surcharge, product loss processing value and milk loss. Water, sewer and surcharge were estimated to cost $111,332/yr or $9278/mo.

Product loss was calculated roughly using the Harper et al. (1971) formula that 1 lb BOD = 9 lb lost milk. First, whey was eliminated from the BOD and drink BOD was disregarded. Product loss was found to be 7,087,500 lbs milk. The value was found to be $708,750 and the process value was estimated at $141,750 annually. The total monthly cost for product loss value and milk loss were $70,875.

Thus, the total monthly cost of water and waste related costs was $80,113.

Management Action Levels

Management Action Levels were established using the Management Action Coefficients (Table 21). The purpose of establishing the Management Action Levels was to help demonstrate the value of management control of water and waste related costs. An initial cost budget and an annual budget were developed.

The authors developed the Management Action Levels as initial levels for analysis of engineering and process changes. The authors found that a management control designation would not easily lend itself to the linear analysis model and its evaluation. The number of activities involved made it difficult to accurately estimate coefficients and assign costs. Therefore, the management control concept was assumed as a prerequisite to any other changes.

Water Use

Water use was estimated following the procedure explained in the Benchmark using 1.43 times the wastewater. Then, the water use was assigned to the processing areas based on the proportion of effluent discharged. Water use was estimated at 36,089,000 gal/yr (Figure 12) or 144,000 gal/day. Water use for fluid processing, cottage cheese and ice cream were estimated to be

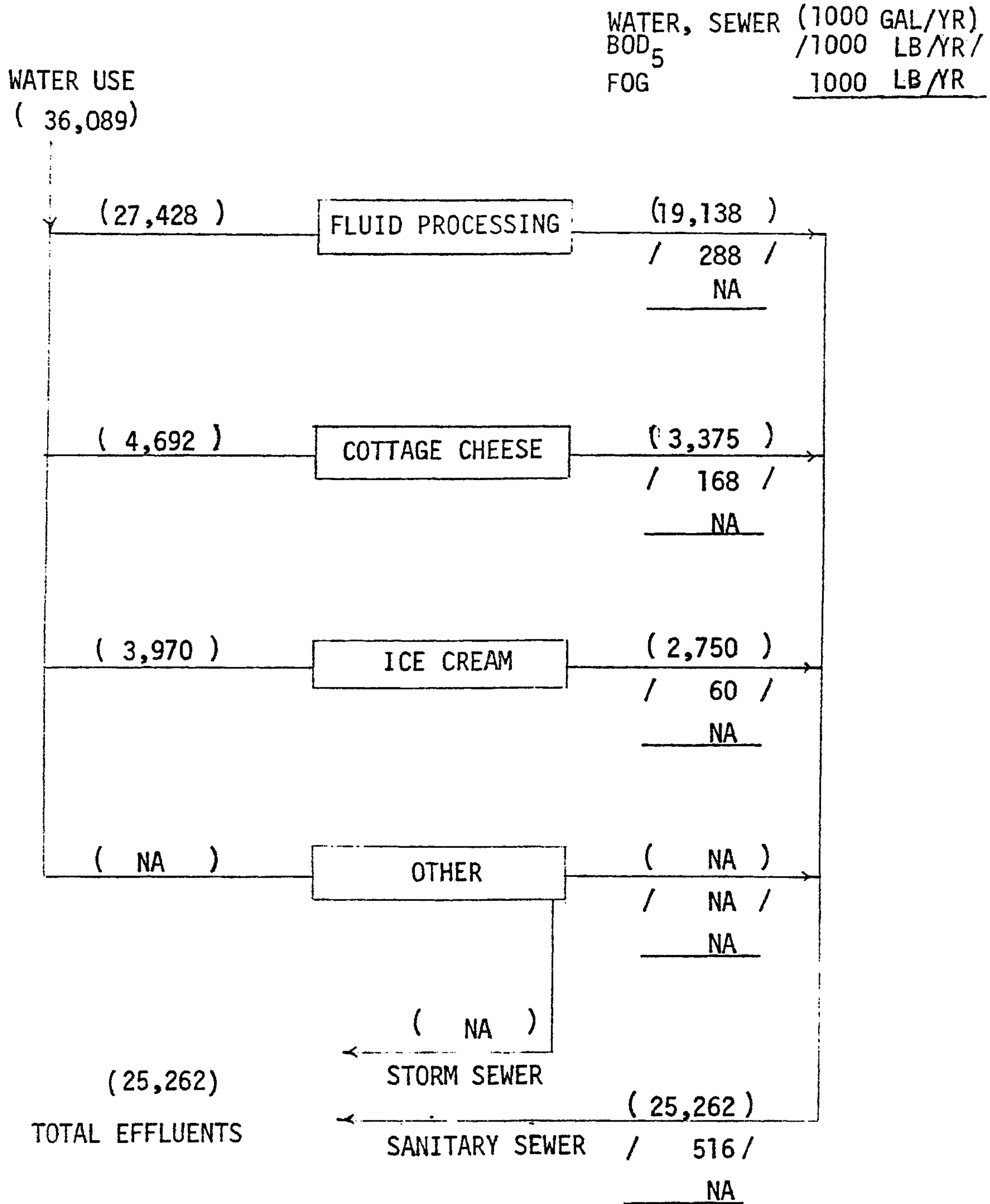


Figure 12. Water Use and Effluents Discharge at the Management Action Level.

27,428,000, 4,692,000 and 3,970,000 gal/yr respectively.

Effluents

Total effluents from the Case Study Plant after management control was estimated to be 25,262,000 gal/yr or 101,000 gal/day. Fluid products processing was estimated to contribute 76% or 19,137,500 gal/yr. Ice cream processing was estimated to contribute 11% of the total effluent for a cheese processing was estimated to discharge 3,375,000 gal/yr or 13% of the total effluents.

Wastewater Characteristics

The BOD concentration of the combined effluents was 2448 mg/l (Figure 12). The BOD concentration of the fluid products processing drain was 1798 mg/l. The BOD concentration estimated for the cottage cheese effluent was 5968 mg/l. The concentration of waste in the ice cream drain was calculated to be 2616 mg/l BOD.

Waste Load

The estimated waste load (BOD) for the Case Study Dairy after management controls were instituted was 515,750 lb/yr or a waste load of some 2063 lb/day. The fluids products processing area was found to contribute 55% of this, or some 285,000 lb/yr. Ice cream processing was estimated to contribute 12% of the load, or some 60,000 lb/yr. And finally, cottage cheese processing contributed the remainder or some 168,000 lb/yr.

Monthly Water and Waste Related Costs

Monthly costs for the Case Study Plant at the Management Action Level would be approximately one-half those monthly costs for the Benchmark. Total monthly costs for water and waste related costs were estimated at $40,678/month. Water, sewer and surcharge were $4633/month or approximately 11% of the total. Total process value of lost products and milk loss cost was found to total $432,540/yr or $36,045/month with an assumed milk loss of 3,604,500 lb/yr.

Initial and Annual Costs

Initial costs for water and waste monitoring and management are presented in Table 27. A major expense was predicted for laboratory renovation, equipment and supplies for wastewater analysis. Water meters were included to assist in water use monitoring as a necessary tool for water management. A sampler and wastewater flow meter were included in the initial costs because they are needed for wastewater monitoring of parameters required by the average sewer use ordinance. Total investment was predicted to be $25,084.

The Annual Budget is presented in Table 28. Increased yearly costs of $51,374 are projected for water and waste management. The major part of these increased costs are for increased labor in two key areas for water and waste management. First, the addition of a water and waste supervisor was included for it has been indicated that he can be the key to efficient plant water and waste control (Carawan and Jones, 1977). Secondly, the addition of two additional men on the maintenance force was suggested as a means of reducing leaks, drips and equipment failures leading to product losses.

The total annual savings of $439,184 as predicted in Table

Table 27. Initial Costs of Dairy Plant Water and Waste Monitoring and Management.

ITEM	QUANTITY AND/OR RATE	AMOUNT[a]	TOTAL[a]
Material:			$ 21,725.
Laboratory Space Renovation - 200 ft^2 @ $25/$ft^2$		5,000	
Laboratory -		8,075	
Equipment $5,575.			
Glassware 1,000.			
Chemicals 1,500.			
Water Meters and Materials		3,000	
Sampler and Flow		3,650	
Sampler with refrigerator	$1,750.		
Flow recorder	1,500.		
Flume and materials	400.		
Flow Regulation (Valves, Gauges, and Materials)		2,000	
Tax:			$ 434.
Installation:			$ 2,925.
225 hrs @ $13			
Total Costs:			$ 25,084.

[a]Based on observations of Carawan *et al*., 1974

Table 28. Annual Budget for Dairy Plant Water and Waste Monitoring and Management.

ITEM	QUANTITY AND/OR RATE	AMOUNT[c]	TOTAL[c]
Reduced Costs:			$130,108
Water Use[a] (Includes sewer cost)			
	36,089,286 gal/yr @ .60/1000 gal	$21,654	
Surcharge[b]			
	517,250 lbs BOD_5/yr @ $.075/lb	38,794	
Processing Value	3,483,500 lbs milk @ $.02/lb	69,660	
Increased Revenue:[c]	3,483,000 lb milk @ $.10/lb		$360,450
Total Savings Per Year			$490,558
Increased Costs:			$ 51,374.
Labor	Water and Waste Supervisor	12,000	
Maintenance	Added space and materials - $2,172. Labor + Materials - increased in maintenance of Process Equipment - $2750/mo.	33,000	
Depreciation	Space $5,000. @ 5% 250. Other @ 20% 3345.	3,595	
Interest		1,129	
Electricity		150	
Chemicals -Laboratory		1,500	
Water			
Net Savings Per Year:			$439,184.

[a]50% reduction from Benchmark
[b]50% reduction from Benchmark
[c]Assumes 90% BOD_5 from milk - 1 lb BOD_5 = 9 lbs milk - after whey BOD_5 removed, as developed by Harper et al., 1971

28 can be questioned as to the magnitude of the savings. This savings assumes that water use and BOD load before the program can be reduced 50% of the assumed Benchmark for the multiproduct dairy plant. However, even if the reduction were half that predicted, the annual savings would exceed $200,000 on an annual cost of $51,374. A return on investment of almost 4 fold would be realized for the Case Study Plant by instituting management control of water and waste.

Water Related Process Alternatives

Nine water use changes for decreasing the water usage in the Case Study Plant were evaluated individually and then collectively by Carawan (1977). The changes were examined by these authors to help demonstrate the collective effect of all applicable changes on the Case Study Dairy.

Some of the water using activities in the dairy, if common industry practice were followed, would have a constant water use not related to the water need of that activity. In instances such as air compressor cooling water and head cooling water for refrigeration compressors, the flows could be constant and not proportional to production or machine running time. Several such changes were evaluated to use control devices to reduce the water usage and made water use responsive to demand.

Another group of changes utilized the concept of the multiple use of water, i. e., the use of water by more than one process - a special kind of water reuse.

A listing of the changes evaluated was included in Table 29. Process alternatives included installing solenoid on the water supply to each of the air compressors to permit water flow only during compressor operation (AIRCOMPC), installing solenoids on the water supply for head cooling of each of the refrigeration compressors for permitting water flow only during compressor operation (REFRIGEB), installing a system to recycle cooling waters from the air compressors effluents and the refrigeration compressor head cooling wastewaters through the cooling compressors (COOLREC), the installation of two single use CIP

Table 29. Water Use Process Alternatives.

Change	Code
Solenoids on Air Compressors	AIRCOMPC
Solenoids on Refrigeration Compressors	REFRIGEB
Recycling System for Cooling Water	COOLREC
Single Use CIP-Rinse Recovery	SURR
Central Hot Water Heater(s) and Hose Nozzles	HOSEUSB
High Pressure Hose Stations	HOSEUSC
Evaporative Condensers	COOLTOWB
Reuse of Truck Wash Water	GARAGESB
Casewasher Water Recycle	CSWASHB

systems with rinse recovery as a replacement for the two reuse systems (SURR), the replacement of hose stations with steam-water mixing tees by a central hot water heater and the installation of nozzles on all the hoses (HOSEUSB), the replacement of most of the "dairy hoses" with high pressure hose stations (HOSEUSC), the replacement of a shell-and-tube system for condensing the refrigeration gasses by water cooling with a cooling system utilizing evaporative condensers (COOLTOWB), the installation of a system to reuse truck wash meters for extended periods of time (GARAGESB).

Collective Evaluation

The nine water use process alternatives were evaluated collectively. A total water reduction for the Case Study Plant was predicted to be 480,688,100 gal/yr (Table 30) if 8 changes were utilized excluding only the installations of central hot water heaters and hose nozzles (HOSEUSB) which is an alternative for high pressure hose station systems (HOSEUSC) which was included. An initital investment of $136,626 was estimated. Net savings per year were estimated to be $133,008 with increased costs $41,370.

The Case Study Plant had been assumed to have a shell and tube condenser system for the refrigeration vapors. This was changed to an evaporative condenser to demonstrate the magnitude of this change. It was expected by the author to have the largest impact on water use that a dairy plant would encounter. If this change (COOLTOWB) were also eliminated from the changes summary, the water reduction for the Case Study Plant would be

Table 30. Water Changes Summary I.[a]

Effect	Amount	Units
Water Reductions	480,688,100	gal/yr
Investments	136,626	$
Increased Costs	41,370	$
Net Savings Per Year	133,008	$

[a]All changes occurring together except for central water heaters and hose nozzles HOSEUSB

Table 31. Water Changes Summary II.[a]

Effect	Amount	Units
Water Reductions	36,207,800	gal/yr
Investments	67,979	$
Increased Costs	14,981	$
Net Savings Per Year	26,053	$

[a]Seven changes included, central water heaters, and hose nozzles (HOSEUSB) and evaporative condensers (COOLTOWB) excluded

36,207,800 gal/yr (Table 31). Investment costs, increased costs and net savings per year were estimated to be $67,979, $14,981 and $26,503 respectively.

A breakdown of the water reduction, % water reduction, initial cost, annual cost and net savings per year is tabulated in Table 32. The greatest water reduction was 444.5 million gal/yr by the evaporative condenser installation (COOLTOWB). The next greatest water reduction was 10 million gal/yr by the recycling of the refrigeration and air compressor cooling waters (COOLREC). The least reduction observed was the recycling of the truck wash water at 1 million gal/yr (GARAGESB). The % water reductions ranged from 36 to 99%.

The ratio of the initial process cost and the water reduction is tabulated in Table 33. Dairy plant management would get the greatest water savings for the dollar invested by utilizing process changes with the lowest ratios first. For example, the alternative of the evaporative condenser contrasted with the shell-and-tube alternative would produce the best results, requiring an investment of only $0.15/1000 gal of annual water reduction. With water assumed to be valued at $0.60/1000 gal for water and sewer, the return to the plant is evident.

However, the concept of return on investment is more commonly used by industrial plant managers to evalute changes. This corresponds to the ratio of net savings per year over initial cost (Table 34). Any ratio over 0.3 will yield the plant a return of investment in the three years that has been reported to these authors as useful for dairy plants.

Table 32. Investment and Annual Costs and Savings for Water Reduction Changes.

Change	Code	Water Reduction (Million Gallons)	Water Reduction (%)	Initial Cost ($)	Increased Cost ($)	Net Savings Per Year ($)
Solenoids on air compressor	AIRCOMPC	2.98	73	732.	101.	1,688.
Recycle of casewasher water	CSWASHB	2.80	93	1,000.	714.	966.
Solenoids on refrigeration compressors	REFRIGEB	5.69	36	1,464.	190.	3,223.
Evaporative condenser	COOLTOWB	444.50	99	68,647.	26,389.	106,955.
Recycle of truck wash water	GARAGESB	1.00	85	2,002.	403.	171.
High pressure hose stations	HOSEUSC	6.31	90	41,935.	9,625.	4,811.
Central hot water and hose nozzles	HOSEUSB	3.51	50	16,676.	3,139.	6,572
Cooling tower recycle for compressors	COOLREC	10.04	90	4,256.	705.	5,321.
Single use, rinse recovery CIP	SURR	7.42	55	16,590.	3,243.	9,873.

Table 33. Annual Water Reductions and Ratio of Initial Change Cost and Water Reductions.

Change	Code	Annual Water Reduction	Initial Process Cost / Water Reduction
		(Million Gallons)	($/1000 gal)
Evaporative condenser	COOLTOWB	444.5	0.15
Cooling tower recycle for compressors	COOLREC	10.0	0.42
Single use, rinse recovery CIP	SURR	7.4	2.23
High pressure hose stations[a]	HOSEUSC	6.3	6.64
Solenoids on refrigeration compressors	REFRIGEB	5.7	0.26
Central hot water and hose nozzles[a]	HOSEUSB	3.5	4.75
Solenoids on air compressor	AIRCOMPC	3.0	0.25
Recycle of truck wash water	GARAGESB	1.0	2.09
Recycle of casewasher water	CSWASHB	2.8	0.36
Total[b]		480.6[a]	
Total		36.2	

[a]HOSEUSB and HOSEUSC are alternatives, HOSEUSC used for total.

[b]COOLTOWB included

Table 34. Ratios of Net Savings Per Year and Annual Cost and Net Savings Per Year and Initial Cost for Water Reduction Changes.

Change	Code	Net Savings Per Year / Increased Annual Cost	Net Savings Per Year / Initial Cost
Solenoids on air Compressor	AIRCOMPC	16.73	2.31
Recycle of casewasher water	CSWASHB	1.35	0.97
Solenoids on refrigeration compressors	REFRIGEB	16.96	2.20
Evaporative condenser	COOLTOWB	4.05	1.56
Recycle of truck wash water	GARAGESB	.32	0.09
High pressure hose stations	HOSEUSC	0.50	0.11
Central hot water and hose nozzles	HOSEUSB	2.09	0.39
Single use, rinse recovery CIP	SURR	3.04	0.60
Cooling tower re-cycle for com-pressors	COOLREC	7.55	1.25

Also, the ratio of net savings per year to increased annual cost was calculated and is displayed in Table 34. The greater this ratio, the more profitable a dairy plant would find any change. The ratios ranged form 0.32 to 16.96. Only the recycle of the truck wash water and the high pressure stations had a savings less than the increased costs.

Waste Related Process Alternatives

Introduction

Thirteen waste related changes for the Case Study Plant which consisted of process alternatives to decrease the BOD load were evaluated collectively and then individually (Carawan, 1977). A number of the changes utilized product-water recovery for use as a raw material. A necessary consideration for these product recovery changes would be that the recovered product would be safe microbiologically and chemically and be legal for use as a product.

The changes do not include all the waste prevention changes that a dairy could make but were selected by the authors to provide insight into the water and waste related parameters that affect such process changes. Primarily, the purpose of the evaluations were to study how such changes could be effectively evaluated and incorporated into the linear analysis model.

Waste related activities of the Case Study Dairy were found to be more easily related to production than the water using activities. The waste related process alternatives evaluated are listed in Table 35. They included: (1) the recovery of the

Table 35. Waste Related Process Alternatives.

Change	Code
Clarifier Sludge Recovery	RMCLB
Collection Tank for Product-Water Residues	COLLECT
Recovery of HTST Start-up and Change Overs	FMHTAS
Drip Shields - Ice Cream Filler	ICFFB
Whey Saving System	WHSV
Fines Recovery-Centrifugal	CCFRC
Returns Recovery	RTSV
Ice Cream Remelt Recovery	RESV
Filler Recovery-Fluid Milk	FMFFC
Fluid Milk Filler Drip Shields	FMFFD
CIP Initial Rinse Recovery-Pasteurized	SURRP
CIP Initial Rinse Recovery-Raw Side	SURRR
High Solids Recovery System	HISOLID

sludge which is automatically washed from the clarifier bowl during the process of clarifying raw milk (RMCLB); (2) the installation of a collection tank (COLLECT) for products or product water mixtures such as returns, filler losses, whey, ice cream residuals, the clarifier sludge from RMCLB and the product-water mixture from the high solids collection system (HISOLID); (3) a system to recover the HTST start-up and change overs which are product-mixture (FMHTAS); (4) the installation of drip shields around the ice cream filler to catch product that for machine or operator error normally goes to the sewer (ICFFB); (5) the installation of a system to assist in the collection of whey rather than its discharge to the sewer (WHSV); (6) the installation of a centrifugal machine (clarifier) to help recover the fines from cottage cheese whey and cottage cheese wash water (CCFRC); (7) the installation of a system to aid in the recovery of fluid milk returns and to send this recovered material to either ice cream products as a raw material or animal feed (RTSV); (8) the installation of a system to aid in the recovery of frozen ice cream that is unable to be packaged (RESV); (9) the installation of a system to aid the fluid milk filler operator in disposing of the milk products from damaged or underfilled cartons (FMFFC); (10) the installation of shields around the fluid product fillers to help contain product that normally would be discharged to the drain (FMFFD); (11) the installation of a system to aid in the recovery for possible product use of the milk-water mixture generated in the initial potable water rinse proposed the CIP system for the pasteurized system on the raw milk CIP system (SURRR); (12) the installation of a similar system on the raw milk CIP system (SURRR); and (13) the installation of a system to aid in the collection for use or disposal of the milk-water mixtures from changes (3), (7), (9), (11) and (12) (HISOLID).

Product and Product-Water Recovery

As previously noted in this study and reviewed, a number of authors previously cited have determined that loss of product into the sewers is the primary source of BOD in dairy processing. The selection of alternatives for product recovering was dependent on the quantity of material (whether product, product-water or by-product, such as whey) that could be collected and eliminated from the sewer.

The possible importance of these collections was evident to the authors as they contacted dairy plants in regard to this study. One dairy reported that they were recovering more than a 1% loss of milk processed just from the initial rinse of raw and and pasteurized CIP systems and the collection of HTST start-ups, change-overs and shutdowns. Another plant was reported collecting CIP-initial rinses, the initial segment of each CIP wash cycle and post-rinse and the same for the HTST cleaning cycles. Plant personnel related that the collection was approximately 8000 gal/day of the material with a reported BOD of 7000 mg/l.

Information reported by Harper et al. (1971) and the Development Document (EPA, 1974) and information solicited from suppliers and processors were used by the authors to formulate expected recovery from product and rinse collection systems. The recoveries estimated for the Case Study Plant are shown in Table 36. Recoveries ranged from 60 gal/day for the centrifugal sludge recovery to 3930 gal/day for the whey recovery change. BOD collected estimates ranged from 100 lb/day for the CP Filler Drip Shields to 1260 lb/day for the Whey Collection System.

A schematic of the recovered product and diluted product systems was shown in Figure 13. Details are given by Carawan (1977). The high solids collection system (HISOLID) was estimated to collect a maximum of 3563 gal/day (Figure 13) of material from the returns salvage (RTSV), the fluid product filler recovery system (FMFFC), the HTST recovery system (FMHTAS), the initial rinse from the pasteurized CIP system (SURRP) and the initial rinse from the raw side CIP system (SURRR). The materials collected in the high solids system (HISOLID) were recovered in a sanitary manner and were able to be used for ice cream in the ice cream blend operation or if not needed in ice cream, could be transferred to the collection tank (COLLECT).

The collection tank (COLLECT) could receive a maximum from all attached recovery systems of 8341 gal/day (Figure 13). The collection tank recovery was assumed only suitable for animal feed (ANIMF) or for disposal to land or other means after truck transport (TRUCK).

Waste Reduction Summary (Collective Evaluation)

Thirteen waste reduction changes were evaluated collectively (Carawan, 1977). The total waste reduction for the Case Study

Table 36. Recovery and Recovered BOD_5 from Waste Related Changes For Case Study Plant.

Change (Code)	Recovery	Recovery	Recovered BOD_5 [a]
	(gal/day)	(lb/day)	(lb/day)
Returns Salvage (RTSV)	930	8000	720
FP Filler Drip Shields (FMFFD)	233	2000	100
IC Filler Drip Shields (ICFFB)	213	2020	163
Whey Collection (WHSV)	3930	34,000	1260
IC Remelt (RESV)	109	1040	270
Clarifier Sludge Recovery (RMCLB)	60	570	285
FP Filler Recovery (FMFFC)	625	5380	267
HTST Recovery (FMHTAS)	600	5160	258
CIP-Initial Rinse-Raw (SURRR)	680	5850	292
CIP-Initial Rinse-Pasteurized (SURRP)	960	8260	413

[a] Estimated using estimated lb BOD_5/lb product from Table 11

IC = Ice Cream
CIP = Cleaning-in-Place
FP = Fluid Products

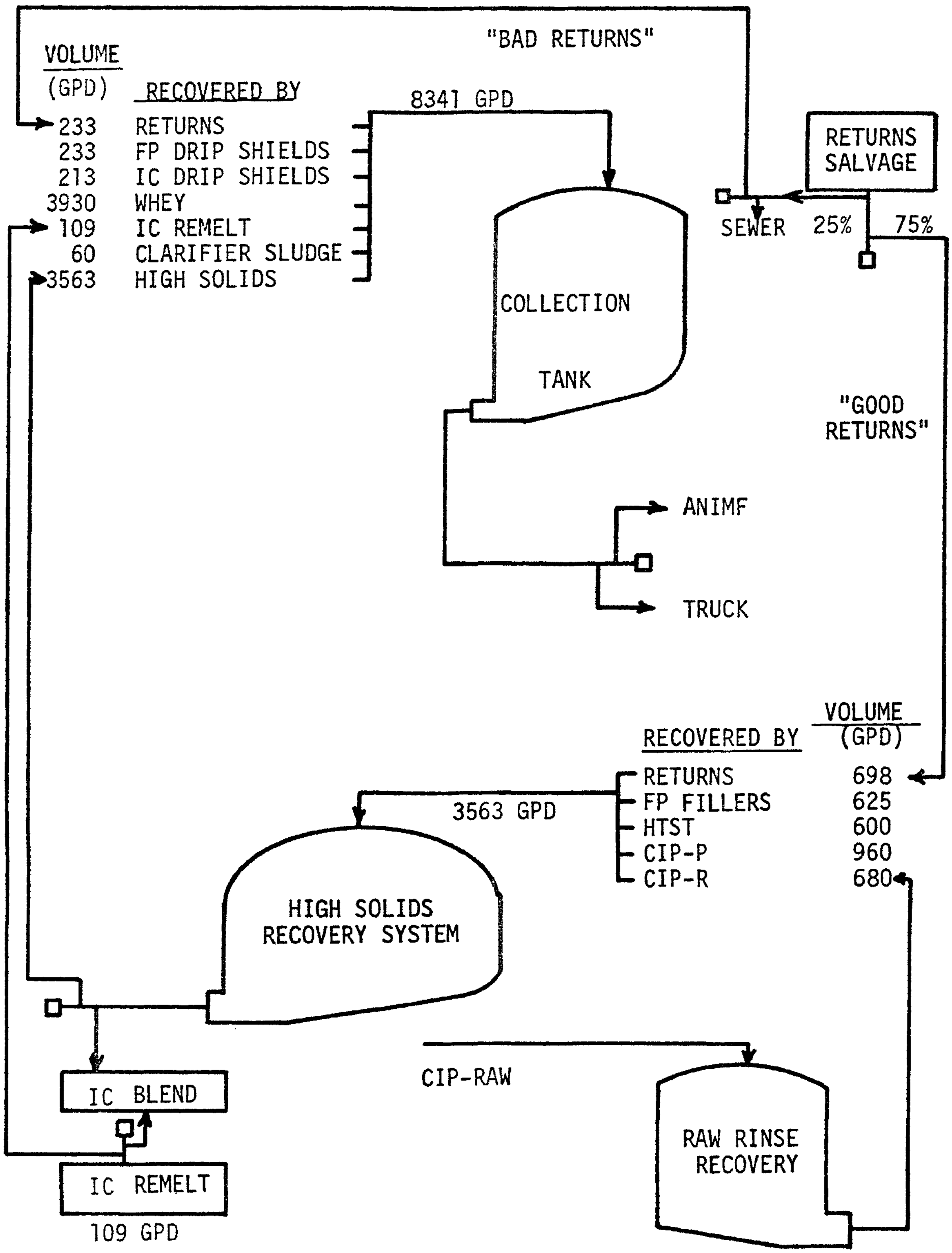


Figure 13. Schematic of Product and Diluted Product Recovery.

Plant was predicted to be 1,055,000 lb/yr of BOD if all thirteen process alternatives were simultaneously, fully implemented (Table 37). An initial investment for the changes was estimated at $174,686. Annual increased costs were estimated to total $78,064. The net savings per year total for the summation of the thirteen changes was found to be $349,389. In addition to the waste reduction, the addition of the process alternatives to the Case Study Plant resulted in an estimated net water use reduction of 170,500 gal/yr. Actually, the water use reduction for the changes was 2,773,000 gal/yr but the implementation of the changes required an increased water use of 2,602,000 gal/yr.

The waste reductions for the individual process alternatives were as follows (Table 38): clarifier sludge recovery (RMCLB), 71,200 lb BOD/yr; HTST recovery system (FMHTAS), 64,500 lb BOD/yr; drip shields on the ice cream fillers (ICFFB), 67,500 lb BOD/yr; whey recovery system (WHSV), 325,000 lb BOD/yr; centrifugal recovery of fines (CCFRC), 14,600 lb BOD/yr; returns recovery (RTSV), 187,000 lb BOD/yr; recovery system for the fluid product fillers (FMFFC), 66,800 lb BOD/yr; drip shield installation on the fluid product fillers (FMFFD), 25,000 lb BOD/yr; initial rinse recovery system for the pasteurized side (SURRP), 103,000 lb BOD/yr; and the initial rinse recovery system for the raw side (SURRR), 73,000 lb BOD/yr.

The initial costs (Table 38) for the process alternatives ranged from $1,501 for the clarifier sludge recovery system (RMCLB) to $43,453 for the centrifugal recovery of fines in the cottage cheese area (CCFRC). Annual increased costs for the

Table 37. Waste Changes Summary.[a]

Effect	Amount	Units
Waste Reduction	1,055.	1000 lb/yr
Investment	174,686	$
Water Use Reduction	2,773	1000 gal/yr
Water Increased Use	2,602	1000 gal/yr
Net Water Use Reduction	170.5	1000 gal/yr
Sewer Reduction	1,857	1000 gal/yr
Net Savings Per Year	349,389	$
Annual Increased Costs	78,064	$

[a]If all changes are fully effective

Table 38. Investment and Annual Costs and Savings for Waste Related Changes.

Change (Code)	Annual BOD_5 Reduction		Initial Cost	Increased Cost	Net Savings[a] Per Year
	(1000 lb)	(%)[b]	($)	($)	($)
Clarifier Sludge Recovery (RMCLB)	71.2	100	1,501	3,142	3,527
Collection Tank for Product - Water Residues (COLLECT)	NA	NA	10,833	4,386	(4,386)
Recovery of HTST Start-up and Change Overs (FMHTAS)	64.5	80	6,117	1,199	36,290
Drip Shields - Ice Cream Filler (ICFFB)	67.5	80	3,881	2,899	7,289
Whey Saving System (WHSV)	315.	80	17,633	5,718	60,702
Fines Recovery - Centrifugal (CCFRC)	14.6	60	43,452	15,435	64,284
Returns Recovery (RTSV)	187.	75	11,043	9,502	42,402
Ice Cream Remelt Recovery (RESV)	67.5	100	14,312	6,080	36,233
Filler Recovery - Fluid Milk (FMFFC)	66.8	90	25,072	12,897	26,171
Fluid Milk Filler Drip Shields (FMFFD)	25.0	80	10,683	5,081	7,357
CIP Initial Rinse Recovery - Pasteurized (SURRP)	103.	80	6,247	2,965	34,310
CIP Initial Rinse Recovery - Raw Side (SURRR)	73.0	80	11,219	4,364	21,942
High Solids Recovery System	NA	NA	12,783	4,896	(4,396)

[a]or Loss

[b]Estimated

process alternatives ranged from $2,899 for the drip shield on the ice cream filler (ICFFB) to the cost of $15,435 for the cottage cheese fines recovery system (CCFRC). The losses shown for the collection tank (COLLECT) and the high solids recovery system (HISOLID) were because no savings were shown for either of these changes as is discussed in the individual evaluation of these changes.

The ratio of increased cost and waste reduction in thousands of pounds were developed and are presented in Table 39. The ratios ranged from $18.2/1000 lb BOD reduction for the whey recovery system to $1060/1000 lb BOD reduction for the centrifugal recovery of cottage cheese fines. Plant management should consider the lower of these first in a planned program to reduce waste load (BOD).

Also shown in Table 39 is the ratio of initial cost and waste (BOD) reduction. The ratios ranged from $21.1/1000 lb BOD reduction for clarifier sludge recovery to $2980/1000 lb BOD reduction for the centrifugal recovery of cottage cheese fines. Management should select the lower ratios first, if the maximum reduction was desired per dollar of investment.

The ratio of net savings per year and increased cost was calculated (Table 40). The range of this ratio was from 1.15 to 30.3 dollars savings per dollar of increased costs. Management should select the largest numerical values first. The ratio of 30.3 was for the recovery system for the HTST system.

In addition, the ratio of net savings per year and initial cost was shown in Table 40. Management should select the largest

Table 39 Ratios of Increased Cost, Initial Cost and Waste (BOD_5) Reductions.

Change (Code)	Increased Cost / Waste Reduction	Initial Cost / Waste Reduction
	(\$/1000 lb BOD_5)	(\$/1000 lb BOD_5)
Clarifier Sludge Recovery (RMCLB)	44.1	21.1
Recovery of HTST Start-up and Change Overs (FMHTAS)	18.6	94.8
Drip Shields - Ice Cream Filler (ICFFB)	43.0	57.5
Whey Saving System (WHSV)	18.2	56.0
Fines Recovery-Centrifugal (CCFRC)	1060.	2980.
Returns Recovery (RTSV)	50.8	59.0
Ice Cream Remelt Recovery (RESV)	88.3	200.
Filler Recovery-Fluid Milk (FMFFC)	193	376
Fluid Milk Filler Drip Shields (FMFFD)	203	426.
CIP Initial Rinse Recovery - Pasteurized (SURRP)	28.7	60.5
CIP Initial Rinse Recovery - Raw Side (SURRR)	59.8	154.

Table 40. Ratio of Net Savings Per Year and Increased Annual Costs and Net Savings Per Year and Initial Cost for Waste Reduction Changes.

Change (Code)	Net Savings Per Year / Annual Increased Costs	Net Savings Per Year / Initial Cost
Clarifier Sludge Recovery (RMCLB)	1.15	2.42
Collection Tank for Product - Water Residues (COLLECT)	NA[a]	NA
Recovery of HTST Start-up and Change Overs (FMHTAS)	30.3	5.93
Drip Shields - Ice Cream Filler (ICFFB)	2.51	1.88
Whey Saving System (WHSV)	10.6	3.44
Fines Recovery-Centrifugal (CCFRC)	4.16	1.48
Returns Recovery (RTSV)	4.46	3.84
Ice Cream Remelt Recovery (RESV)	6.15	2.72
Filler Recovery-Fluid Milk (FMFFC)	2.03	1.04
Fluid Milk Filler Drip Shields (FMFFD)	2.16	0.69
CIP Initial Rinse Recovery - Pasteurized (SURRP)	17.26	5.49
CIP Initial Rinse Recovery - Raw Side (SURRR)	4.78	1.96
High Solids Recovery System (HISOLID)	NA	NA

[a]NA = not applicable

system. The smallest ratio was 0.69 dollars net savings per dollar initial cost for the drip shields on the fluid product fillers (FMFFD).

Summary of Changes

Water Reduction

Water use in the Case Study Plant was reduced from the Benchmark (Figure 11) by 516,948,000 gal (Table 41) with the incorporation of Management Action (Table 21), Waste Changes (Table 37) and Water Changes (Table 30). The water use reduction was 36,138,300 gal/yr if the Case Study Plant was assumed to already have an evaporative condenser (COOLTOWB) which was responsible for a 444,550,000 gal/yr water reduction. Using the smaller of the two reductions of the daily decrease in water use for the plant would be 144,552 gal.

Waste Reduction

The waste load (BOD) for the Case Study Plant could be reduced by 1,572,250 lb/yr with the incorporation of all the changes suggested in the Management Action section and the Waste Changes section. Based on a 250 work day year, this reduction would represent a daily reduction of 6289 lb/yr. Considering that Harper *et al*. (1971) reported that the very large plants seldom have waste loads greater than 8 to 10,000 lb BOD/day, the proposed reduction is very large for a plant with less than one-half of the production of a large plant.

Costs and Savings

The summation of the initial costs are presented in Table

Table 41. Effect of Water and Waste Reduction Changes on Case Study Plant.

Effect Change	Amount	Units
Waste Reduction (BOD_5)		
Management Action	517,250	lb
Waste Changes	1,055,000	lb
Total	1,572,250	lb
Water Reduction		
Management Action	36,089,286	gal
Water Changes	480,688,100	gal
Waste Changes	170,500	gal
Total	516,947,886	
Initial Costs		
Management Action	25,084	$
Water Changes	136,626	$
Waste Changes	174,686	$
Total	336,396	$
Increased Costs		
Management Action	51,374	$
Water Changes	41,370	$
Waste Changes	78,064	$
Total	170,808	$
Net Savings Per Year		
Management Action	439,184	$
Water Changes	133,008	$
Waste Changes	349,389	$
Total	921,581	$

Costs and Savings

The summation of the initial costs are presented in Table 41. Total initial costs for the Management Action, Waste Changes and Water Changes were calculated to be $336,396.

Increased costs were estimated to total $170,808. Net savings per year were estimated to total $921,581. The ratio of net savings per year and increased costs was calculated to be 5.4, i.e., 5.4 dollars of savings per dollar of increased costs.

The ratio of net savings per year for all the changes and the initial costs or investment was found to be 2.74. In other words, there were annual savings of 2.74 dollars for each dollar of initial investment.

Linear Analysis Model

A linear analysis model of the Case Study Plant was developed and evaluated for its applicability to evaluating water and waste related activities in dairy processing. The effects on the Case Study Plant of the following were examined using successive solutions the linear programming model: (a) increasing water costs, (b) increasing surcharge costs for BOD, (c) effluent limitations on BOD, (d) effluent limitations on FOG and (e) combinations of (a) through (d) in conjunction with a group of process alternatives selected from those water reduction and waste reduction changes examined previously in this study.

Features of Model

The LP Model for the Case Study Plant was designed to represent a typical multiproduct, medium-size dairy plant.

Emphasis was placed on any process or operation (activity) which related to water and waste related costs. The objective function was minimized to select the least cost of all water and waste related costs which included assumed values for all products.

An option built into the model was the ability of the Case Study Plant to purchase major products (FM, CC, IC) that could not be optimally processed due to costs of water and waste related parameters or due to restrictions imposed on the sewer discharge for either BOD or FOG. When the cost of the raw products and water and related costs exceeded the buy cost for any product the product buy activity will enter the solution.

The Model

Information needed for the model included definition of activity activities, activity coefficients, cost coefficients for the objective function, internal restrictions for the activities and external restrictions for the model. A representative section of the model is presented in Figure 14. A complete overview of the model is presented as the computer (PICTURE) output for the BASIS V solution (CASESTUD) in Figure 18 in Appendix A.

Objective Function. The objective of the model as presented was to select the least cost of all water and waste related activities including raw product costs. These are shown in Figure 14 as the OBJECTIVE FUNCTION (f) and the cost coefficients (C_j's). Cost minimization was chosen for the solutions; i.e., any solution identifies the minimum $f = \sum c_j$ for the activities presented that satisfies both the internal and external model restrictions.

ROWS	Product Inputs X_a	X_b	Production Processes X_c	X_d	X_e	X_f	Product X_g	Water Supply X_h	Sewer Discharge X_i	Waste Parameter X_j	Product Loss X_k	Product Recovery X_l	Use of Recovered Product X_m	Collection X_n	Animal Feed Sales X_o	Truck Disposal X_p		RHS Constraints
a. Input availability	-1	-1	1										-1				=	b_a
b. Product mix requirement	a_{ba}	$-a_{bb}$	a_{bc}										$-a_{bm}$				$\geq$	b_b
c. Transfer, X_c to X_d			$-a_{cc}$	1													$\leq$	b_c
d. Transfer, from X_d				$-a_{dd}$	1	1											$\leq$	b_d
e. Transfer, to X_g					$-a_{ee}$	$-a_{ef}$	1										$\leq$	b_e
f Minimum production							.001										$\geq$	b_f
g. Water Use			a_{gc}	a_{gd}	a_{ge}	a_{gf}		-1000									=	b_g
h. Sewer discharge			$-a_{hc}$	$-a_{hd}$	$-a_{he}$	$-a_{hf}$			1000								=	b_h
i. Waste discharge			$-a_{ic}$	$-a_{id}$	$-a_{ie}$	$-a_{if}$				1000							=	b_i
j Product loss			$-a_{jc}$	$-a_{jd}$	$-a_{je}$	$-a_{jf}$					1000						=	b_j
k. Maximum waste concentration									-CF	.1199							$\leq$	b_k
l. Product recovery			$-a_{lc}$	$-a_{ld}$	$-a_{le}$	$-a_{lf}$						1					$\leq$	b_l
m. Non-sanitary recovery			$-a_{mc}$	$-a_{md}$	$-a_{me}$	$-a_{mf}$								1			$\leq$	b_m
n. Transfer, to X_m												-1	1				$\leq$	b_n
o. Transfer of collected materials														-1	1	1	=	b_o
OBJECTIVE FUNCTION	c_a Costs of inputs	c_b				c_f cost of alternative process		c_h cost of water		c_j Cost for waste discharge		c_l Cost of recovery system		c_n Cost of collection system	$-c_o$ Value of sales	c_p Cost for disposal	=	f(minimize)

CF = Wastewater parameter restriction factor = Concentration (mg/l)/1,000,000

Figure 14. Representative Segment of Case Study Plant Model.

The objective function shown in Figure 14 includes the cost of inputs (c_a and c_b), the increased cost of the process alternative (c_f), the cost of water (c_h), the cost for waste discharge (c_j), the increased cost of the recovery system (c_l), the increased cost of the collection system (c_n), the value of animal feed sales (c_o) and the cost of truck disposal.

Restrictions. The restrictions are shown in Figure 14 as the right hand sides (RHS) which are identified for each row with an equality or inequality and a value as given by the b_i's. Internal restrictions inherent in the manufacturing processes have $b_i = 0$ while external restrictions have bi = some value. A less than (L) restriction was used to make supply greater than demand except for buttermilk transfers, mix or blend activities and water use, sewer discharge, BOD and FOG transfers which needed to be equalities for the model to function.

Activities. The activities (ACTIVITIES) for the section of the model are shown in Figure 14. They are fully described in Appendix A. The process activities include the supply of production inputs or raw materials (X_a and X_b) and recovered materials used for product (X_m), the process sequence involving first a blend or mix process (X_c) followed by two production processes (X_d and X_e) and an alternative process for X_e (X_f) which combine to give product (X_g).

For each of the production processes the activity coefficients (a_{ij} values) specify the use or contribution of that activity to water, waste, wastewater, product loss, product recovery and transfer of the product to the next sequential activity.

Other activities shown in Figure 14 are water supply (X_h), sewer discharge (X_i), waste parameter discharge (X_j), product loss (X_k), sanitary product recovery (X_l), use of sanitarily recovered product (X_m), and collection of water-product mixtures (X_n) for disposal as animal feed (X_o) or truck disposal (X_p).

Rows. The ROWS shown in Figure 14 equate the linear relationship of the activities through the activity coefficients and the RHS's. ROWS shown in Figure 14 include input availability (a), product mix (b), product transfers (c, d, e, n and o), product production requirement (f), water use supply (g), sewer discharge contribution (g), waste discharge (i), product loss (j), maximum waste restriction (k), product recovery (l) and non-sanitary recovery (m). The RHS's restrict the activity of each row subject to the equality or inequality placed on that row.

Coefficients for the Model

Cost Coefficients. Cost coefficients (c_j) for product inputs, sales, buys and disposal activities were estimated by the authors using industry data as a base. Cost coefficients for alternative processes introduced into the model were determined by dividing the increased annual costs obtained from the Annual Budget(s) for the change(s) presented in this study by the anticipated production through the process alternative activity. Cost coefficients were expressed in dollars/pound except that water and sewer cost coefficients were expressed as dollars/gallon.

Activity Coefficients. The development of the activity coefficients (a_{ij}'s) proceeded as follows. A consistent sign convention was followed in that a negative sign was assigned to the activity coefficient for any activity supplying something to another activity; i.e., water supply has an activity coefficient of 1000 for the water supply activity in ROW (g) in Figure 14.

The units of the activity coefficients were determined by examining the units of the activities and making unit consistancy for the rows. Activities had units of pounds (lb) except for water and sewer activities which are given in gallons (gal). Activity coefficients were expressed in lb/lb except for water use, sewer discharge, product loss, BOD discharge and FOG discharge. Water use and sewer discharge activity coefficients were expressed as gal/1000 lb of activity. Product loss, BOD discharge and FOG discharge activity coefficients were expressed as lb/1000 of activity.

A special case was used for the product transfer coefficients where product was lost in the activity. In these cases, the transfer coefficient from that activity was developed by subtracting the absolute value of the loss activity coefficient (lb/1000 lb) divided by 1000 lb from one. For example, in Figure 14, production activity X_e has a loss coefficient (a_{je}) which was divided by 1000 and subtracted from 1 equals $1 - a_{je}/1000$. This expression equals the activity transfer coefficient for product from X_e to X_g of a_{ee}.

Another special requirement for activity coefficients was created by the desire to impose maximum waste parameter concentrations on the sewer discharge. The activity coefficients used were developed as follows and can be observed in Figure 14. The activity coefficient was found by restricting the waste parameter concentration in the wastewater as follows:

Waste Parameter (lb)		Sewer Discharge (lb)
.1199	$\leq$	-CF

where .1199 = 1 lb/8.34 lb/gal

and $CF = \frac{\text{concentration}}{1,000,000}$

The negative sign on the concentration factor (CF) makes CF the RHS for the row, as $b_k = 0$.

The coefficients developed for the model were selected for application to the Case Study Plant. The coefficients were selected to be as representative of real dairy operations as possible. The previous hand calculations were used to confirm the accuracy and usefulness of the coefficients.

Differences in Model and Previous Results

The incorporation of the process alternatives into the model required the modification of the coefficients previously presented for the Case Study Plant to accommodate the changes in the model. Fines and whey were added into activity CCWA based on the data of Harper (1974). The casewasher was assumed to be part of the fluid milk filling activity (FMFF). The water and sewer values were changed to reflect their values as found by Carawan et al. (1972). The ice cream filling (ICFF) waste coefficient was considered low based on discussions with dairy persons and increased. Raw milk receiving (RMRC) was expanded to include clarification of raw milk. Fluid milk filling (FMSF) waste coefficient was increased based on the observation of these authors that it did reflect a real dairy plant. The ice cream continuous freezer (ICAF) waste load coefficient was increased to more accurately reflect observed dairy plant losses. Coefficients for floor cleaning and COP cleaning tanks were incorporated into the filled storage activity (SF) which also was expanded to show distribution losses, water use, etc. Coefficients for the BOD load of cleaning chemicals was assigned to the pasteurization step for each product to simplify programming.

Process Alternatives

Process alternatives selected for incorporation into the linear model are shown in Table 42. They were selected based on the ease of incorporation in the model and the information developed during the hand calculations of this study. Twenty-six process alternatives or combinations of alternatives were selected. A description of each process alternatives is presented in Table 42. and the complete development of each change has been previously elaborated by Carawan (1977). In some cases as shown in Table 42, the coding of the changes was modified for the computer studies to simplify the model.

The diagram of the high solids recovery system as used in the model is shown in Figure 15. Similarly, the collection system is shown in Figure 16.

Table 42. Listing of Process Alternatives.

Process Alternative Code	Description[b]
OTHERB	Same[a] as COOLTOWB, installation and use of evaporative condenser.
OTHERC	Combination of AIRCOMPC and REFRIGEB, solenoids on head cooling water supply.
OTHERD	Combination of COOLTOWB, AIRCOMPC, REFRIGEB, COLLREC which was the cooling water recycle system for air and refrigeration compressors, and GARAGESB which was the truck wash recycle system.
FMFFB	Same[a] as CSWASHB, case washer water recycle system.
FMFFC	Fluid milk filler recovery system.
FMFFD	Fluid milk filler drip shields.
FMFFE	Combination of FMFFB, FMFFC and FMFFD.
CCWAB	Same[a] as WHSV, whey recovery system.
CCWAC	Same[a] as CCFRC, centrifugal recovery system for cottage cheese fines.
CCWAD	Combination of CCWAB and CCWAC.
COLLECT COLL(1 to 6)	System to recover product or product water mixtures for either animal feed sales (ANIMF) or truck disposal (TRUCK) - seven components.
HISOLID HISOL(1 + 2)	System to sanitarily recover product-water mixtures for use (RHUS) through collection system - three components.
FMHTAS	System to recover HTST start-up, change-overs and shut-down product-water mixtures.
RMRCB	Same[a] as RMCLB, system to recover clarifier sludge.
FMSFB	Same[a] as RTSV, system to recover returns.
ICAFB	Same[a] as RESV, system to recover ice cream.
ICFFB	Drip shields on the ice cream filler.

[a]Same = Same change

[b]Coding of changes refers to process alternatives evaluated in this study

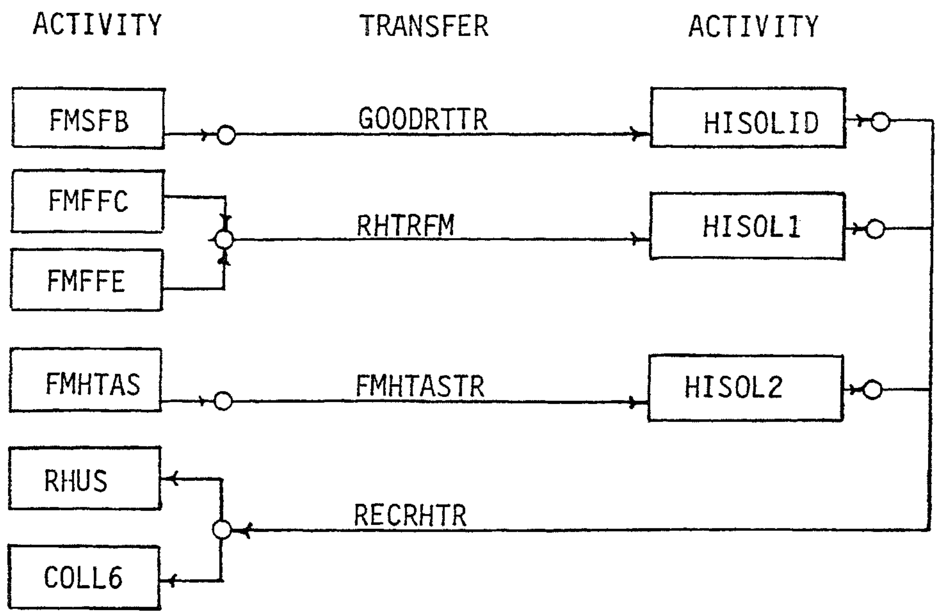


Figure 15. Computer Coding for High Solids Recovery System

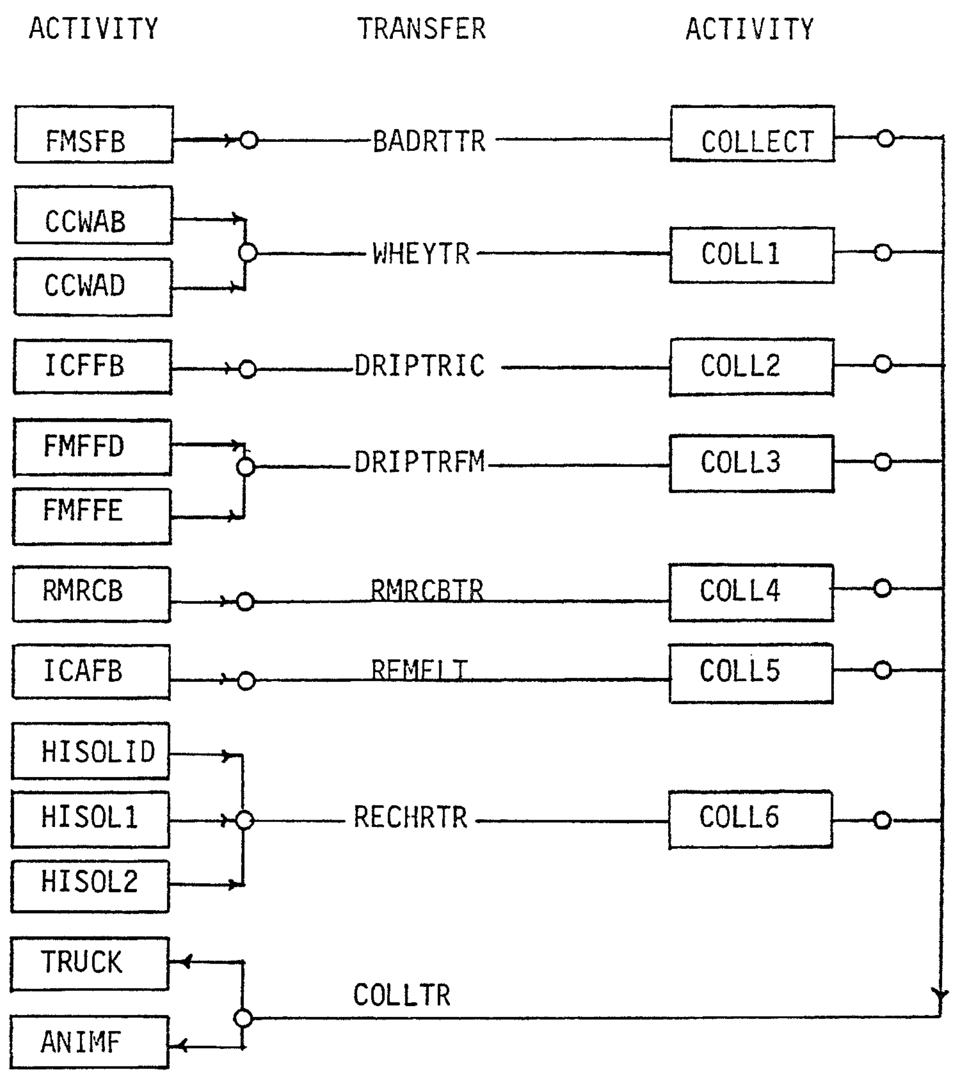


Figure 16. Computer Coding for Collection System

Linear Programming Solutions

Solutions of Model

Twenty-seven solutions were attempted for the linear programming model of the Case Study Plant. The solutions were identified as shown in Table 43. Variables utilized in the solution included loss cost coefficients, water cost coefficients, surcharge cost coefficients, BOD discharge coefficients and FOG discharge coefficients; as well as having no process alternatives available, having only the evaporative condenser option (OTHERB) or having all process alternatives available.

Basic Solutions

Five basic solutions were made as presented in Table 44. The value of the objective function ranged from $9.966 million to $16.12 million. Water use was found to range from 514 to 13.7 million gallons. BOD discharge was found to range from 1.7 to 0.212 million pounds. The Basis Solution V (CASESTUD) had both a BOD restriction of 2000 mg/l and a FOG restriction of 250mg/l. In this solution, no ice cream could be produced by the Case Study Plant and only 6% of the fluid milk and 64% of the cottage cheese demand could be satisfied. The basic solutions were used for comparison with the other solutions.

Effect of Water Cost

Water cost was ranged from $.0001/gal to $.002/gal to observe the effect on the Case Study Plant. The results are presented in Table 44. As a basis, CASESTYB and CASESTYC are also presented. At water costs above $.001/gal, all process

Table 43. Identification of Solutions for Case Study Plant Linear Programming Model.

Problem Name Code	Cost Coefficients[a] BUYWAT ($/gal)	SURCHB ($/lb)	Concentration Restriction BOD_5 (mg/l)	FOG (mg/l)
	No Process Alternatives Available			
CASESTYA	.0001			
CASESTYB	.0001			
	With Only OTHERB Process Alternative Available			
CASESTYC	.0001			
CASESTYS	.0006	.075		
CASESTYT	.0006	.075	2000	
CASESTYU	.0006	.075	1000	
CASESTYV	.0006	.075	250	
CASESTYW	.0006	.075		250
CASESTYX	.0006	.075		100
CASESTYY	.0006	.075		50
CASESTYZ	.0006	.075		25
	With All Process Alternatives Available			
CASESTUD	.0006	.075	2000	250
CASESTYD	.0001			
CASESTYE	.0006			
CASESTYF	.001			
CASESTYG	.002			
CASESTYH	.0006	.04		
CASESTYI	.0006	.075		
CASESTYJ	.0006	.125		
CASESTYK	.0006	.20		
CASESTYL	.0006	.075	2000	
CASESTYM	.0006	.075	1000	
CASESTYN	.0006	.075	250	
CASESTYO	.0006	.075		250
CASESTYP	.0006	.075		100
CASESTYQ	.0006	.075		50
CASESTYR	.0006	.075		25

[a]No product loss coefficients for CASESTYA, all other solutions had RMLOSS = $.005/lb, FMLOSS = $.02/lb, CCLOSS = $.15/lb and ICLOSS = $.05/lb

Table 44. Basic Solutions of Linear Programming Model of Case Study Plant.

Basis	Problem Name Code	Objective Function (M $)	Water Cost ($/gal)	Water Use (M gal)	Surcharge Cost ($/lb BOD_5)	BOD_5 (M lb)	FOG (M lb)	Description of Solution
				No Process Alternatives				
I	CASESTYA	9.966	.0001	514		1.70	.317	a) No product loss cost coefficients
II	CASESTYB	10.16	.0001	514		1.70	.317	b) With product loss cost coefficients
				Only OTHERB				
III	CASESTYC	10.14	.0001	69.5		1.70	.317	a) No surcharge
IV	CASESTYS	10.30	.0006	69.5	.075	1.70	.317	b) With surcharge
				All Process Alternatives Available				
V	CASESTUD	16.12	.0006	13.7	.075	.212	.026	a) BOD_5 maximum = 2000 mg/l b) FOG maximum = 250 mg/l c) Alternatives used includeed FMSFB, FMFFC, FMHTAS, OTHERD, CCWAD and RMRCB. e) Production of 6% of FM, 64% of CC and 0% of IC

M = Million

alternatives selected for each solution were the same (Table 45). Even the lowest water cost of $.001/gal, the use of the evaporative condenser OTHERB was selected over the shell-and-tube condenser OTHERD. A number of waste reduction changes entered the solutions with the water changes. These are shown in Table 46. This reflects the decreased costs of product associated with recovering product for use or disposing of it other than to the municipality. The difference in the objective function for the four solutions was $64,000.

Effect of Surcharge Cost

Surcharge cost was ranged from $.04 to $.20/lb BOD as shown in Table 47. The value of the objective function change by $120,000 over this range of surcharge costs.

Process alternatives entered the solution as shown in Table 48. Only RMRB (the change recovering the clarifier sludge) stayed out of the solution at a surcharge cost of $.04/lb BOD. At higher values, this change entered the solution. The changes in the objective function above $0.04/lb BOD were only a result of the increasing surcharges.

Effect of BOD Concentration Restriction

Concentration discharge limitations for BOD were evaluated using the linear programming model for the Case Study Plant. The effects on water and waste related parameters are presented in Table 49. Most significant was the finding that even a BOD discharge limitation restriction of 2000 mg/l left the Case Study Plant with the capability of producing only 25% of the fluid milk products and no ice cream or cottage cheese without process

Table 45. Effect of Water Cost on Annual Levels of Water and Waste Related Activities.

Problem Name Code[a]	Water Cost	Objective Function	Water Use	Sanitary Sewer	BOD_5	FOG
	($/gal)	(M $)	(M gal)	(M gal)	(M lb)	(M lb)
	All Process Alternatives Available					
CASESTYD	.0001	9.406	63.2	36.0	.826	.158
CASESTYE	.0006	9.409	43.5	36.0	.826	.158
CASESTYF	.001	9.426	43.5	36.0	.826	.158
CASESTYG	.002	9.470	43.5	36.0	.826	.158
	No Process Alternatives Available					
CASESTYB	.001	10.15	514.	42.5	1.70	.317
	Only COOLTOWB Available					
CASESTYC	.001	10.14	69.5	42.5	1.70	.317

[a]RMLOSS = $.005/lb; FMLOSS = $.02/lb;
ICLOSS = $.05/lb; CCLOSS = $.15/lb

M = Million

Table 46. Effect of Water Cost on Process Alternative Activity.

Problem Name Code	Process Alternatives[a] ICFFB	FMSFB	FMHTAS	FMFFE	OTHERB	OTHERD	CCWAD	RMRCB	ICAFB	Water Cost ($/gal)
CASESTYD	X	X	X	X	X		X		X	.0001
CASESTYE	X	X	X	X		X	X		X	.0006
CASESTYF	X	X	X	X		X	X		X	.001
CASESTYG	X	X	X	X		X	X		X	.002
CASESTYB	-	-	-	-	-	-	-	-	-	.0001
CASESTYC	-	-	-	-	X	-	-	-	-	.0001

[a]Process alternatives not shown did not enter any of the solutions listed.

Code: - = Not available in this solution.
X = Activity use in this solution.

Table 47. Effect of Surcharge (BOD_5) Cost on Annual Levels of Water and Waste Related Activities.

Problem Name Code[a,b]	Surcharge Cost	Objective Function	Water Use	Sewer Discharge	BOD_5	FOG
	(\$/lb BOD_5)	(M \$)	(M gal)	(M gal)	(M lb)	(M lb)
CASESTYH	.04	9.442	43.5	36.0	.826	.158
CASESTYI	.075	9.468	43.5	36.0	.749	.159
CASESTYJ	.125	9.506	43.5	36.0	.749	.159
CASESTYK	.20	9.562	43.5	36.0	.749	.159

[a]RMLOSS = \$.005/lb; FMLOSS = \$.02/lb; ICLOSS = \$.05/lb; CCLOSS = \$.15/lb and BUYWAT = \$.0006/gal.

[b]All Process Alternatives Available

Table 48. Effect of Surcharge Cost on Process Alternative Activity.

Problem Name Code	Process Alternatives[a] ICFFB	FMSFB	FMHTAS	FMFFE	OTHERD	CCWAD	RMRCB	ICAFB	Surcharge Cost (\$/lb BOD_5)
CASESTYH	X	X	X	X	X	X		X	.04
CASESTYI	X	X	X	X	X	X	X	X	.075
CASESTYJ	X	X	X	X	X	X	X	X	.125
CASESTYK	X	X	X	X	X	X	X	X	.2

[a]All process alternatives available, those with no use for these solutions not shown, see Table 42 for code designations

Code: X = Activity in this solution.

Table 49. Effect of Sanitary Sewer BOD_5 Concentration Limitation on Annual Levels of Water and Waste Related Parameters.

Problem Name Code[a]	BOD_5 Restriction	Objective Function	Water Use	Sanitary Sewer	BOD_5	FOG	Products Bought: Fluid Milk	Products Bought: Cottage Cheese	Products Bought: Ice Cream
	(mg/l)	(M[c] $)	(M gal)	(M gal)	(M lb)	(M lb)	(%)	(%)	(%)
Only OTHERB Available									
CASESTYS	NA	10.30	69.5	42.5	1.70	.317	0	0	0
CASESTYT	2000	15.40	23.8	16.0	.266	.069	75	100	100
CASESTYU	1000	16.52	12.0	2.7	.078	.023	97	100	100
CASESTYV	250	IF[b]	IF	IF	IF	IF	IF	IF	IF
All Process Alternatives Available									
CASESTYL	2000	9.8	44.3	36.8	.614	.162	0	77	0
CASESTYM	1000	16.05	13.0	11.7	.089	.03	88	100	100
CASESTYN	250	IF	IF	IF	IF	IF	IF	IF	IF

[a] RMLOSS = $.005/lb; FMLOSS = $.02/lb; ICLOSS = $.05/lb; CCLOSS = $.15/lb; SURCHB = $.075/lb

[b] IF = Infeasible Solution

[c] M = Million

alternatives. With all available process alternatives at the BOD restriction of 2000 mg/l, the Case Study Plant could produce all the needed fluid milk, 23% of the needed cottage cheese and all the needed ice cream. Even with the process alternative, a BOD restriction of 250 mg/l provided an infeasible solution.

Table 50 displays the process alternative activity with the various levels of BOD restriction. The use of process alternatives in The Case Study Plant was often precluded because the BOD limitations prevented product production even with changes. For example, in Table 50, CCWAD could not enter the solution (CASESTYM) as no cottage cheese could optimally be processed (Table 49) even with the water and waste reductions as CCWAD.

Effect of FOG Concentration Restriction

Concentration discharge limitations for FOG restrictions from 250 mg/l to 25 mg/l are presented in Table 51. Without process changes (Table 52) other than OTHERB, the FOG restrictions precluded the production of products except at the 250 mg/l level. At this least limiting restriction, only 3% of the fluid milk products could be produced. With the process alternatives available and a FOG restriction of 250 mg/l, 100% cottage cheese production was possible with 8% fluid milk production.

The results in Table 51 present an unusual picture. As production of products decreases, the water use, sanitary sewer and the BOD show increases. This was because inequalities used for product transfers allowed excess raw materials to be run

Table 50. Effect of Sanitary Sewer BOD_5 Concentration Limitation on Process Alternative Activity.

Problem Name Code	BOD_5 Restriction (mg/l)	Process Alternative[a]									
		ICFFB	FMSFB	FMFFC	FMHTAS	FMFFE	OTHERB	OTHERD	CCWAD	RMRCB	ICAFB
CASESTYS		-	-	-	-	-	X	-	-	-	-
CASESTYT	2000	-	-	-	-	-	X	-	-	-	-
CASESTYU	1000	-	-	-	-	-	X	-	-	-	-
CASESTYV	250	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF
CASESTYL	2000	X	X	X	X			X	X	X	X
CASESTYM	1000		X		X			X		X	
CASESTYN	250	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF

Code: - = Not available in this solution
X = Activity use in this solution
IF = Infeasible Solution

[a]See Table 97 for code designations

Table 51. Effect of Sanitary Sewer FOG Concentration Limitation on Annual Levels of Water and Waste Related Parameters.

Problem Name Code[a]	FOG Restriction	Objective Function	Water Use	Sanitary Sewer	BOD_5	FOG	Products Bought: Fluid Milk	Products Bought: Cottage Cheese	Products Bought: Ice Cream
	(mg/l)	(M $)	(M gal)	(M gal)	(M lb)	(M lb)	(%)	(%)	(%)
Only OTHERB Available									
CASESTYW	250	16.23	15.5	12.6	.616	.026	97	100	100
CASESTYX	100	20.96	21.9	19.7	.276	.016	100	100	100
CASESTYY	50	28.40	42.0	39.4	.067	.016	100	100	100
CASESTYZ	25	43.27	82.2	78.9	1.46	.016	100	100	100
All Process Alternatives Available									
CASESTYO	250	15.85	15.7	14.5	.336	.030	92	0	100
CASESTYP	100	24.5	24.5	23.7	.512	.020	100	0	100
CASESTYQ	50	40.5	40.5	39.4	.671	.016	100	100	100
CASESTYR	25	43.27	80.7	78.9	1.46	0.016	100	100	100

[a]RMLOSS = $.005/lb; FMLOSS = $.02/lb; CCLOSS = $.15/lb; ICLOSS = $.05/lb; SURCHB = $.075/lb

Table 52. Effect of Sanitary Sewer FOG Concentration Limitation on Process Alternative Activity.

		Process Alternatives[a]							
Problem Name Code	FOG Restriction (mg/l)	FMSFB	FMSFC	FMHTAS	FMFFE	OTHERB	OTHERD	CCWAD	CCWAB
CASESTYS		-	-	-	-	X	-	-	-
CASESTYW	250	-	-	-	-	X	-	-	-
CASESTYX	100	-	-	-	-	X	-	-	-
CASESTYY	50	-	-	-	-	X	-	-	-
CASESTYZ	25	-	-	-	-	X	-	-	-
CASESTYO	250	X	X	X			X		X
CASESTYP	100						X	X	
CASESTYQ	50						X		
CASESTYR	25						X		

Code: - = Not available in this solution
X = Activity use in this solution

[a]See Table 42 for code designations

through activities with the desired final product produced. The residual product was left in slack activity for the row. Slack activity is the difference between the equality restriction and the activity level of the row. For example, in CASESTYR the activity OJCV showed a value of 1,410,174,816 lb while OJSF showed a value of 750,000 lb. In reality, it would be infeasible to buy water and product and let it flow to the drain. However, many plants now may buy excess water to meet effluent limitations imposed by cities.

The model can be improved by making buy product coefficients more indicative of costs, by using equalities for all product transfer rows for all activities from blend through storage for each product as was done for buttermilk after initial solutions indicated a similar problem or by putting an input-output restriction on products.

The buy coefficients used for fluid milk, cottage cheese and ice cream were estimated by the authors based on information supplied by dairies. They were selected to represent wholesale costs. The buy activity enters any solution when raw product costs and the water and waste related costs exceed the buy cost.

Thus, the processing costs for products did not include labor, containers, utilities or chemicals except those excesses of these utilized for alternative processes. The authors had three reasons not to utilize actual dairy processing costs for products. The reasons were as follows:

1) The authors believe that accounting records for dairies often do not reflect a valid materials

balance. Therefore, costs calculated from these records are not accurate.

2) The authors tried to isolate only those costs related to water and wastes activities.

3) True processing costs would show a lesser difference between the costs of processing a product and buying a product. Thus, the full range of costs and restrictions was believed to be threatened with infeasible solutions.

Thus, the Case Study Dairy model is probably less sensitive to change than would be an actual dairy because processing costs are understated. The authors realized this, though, in the model formulation and this was not changed to allow greater cost and effluent restriction variation than was believed possible with more realistic assumptions. Also, the model was realized to be less sensitive to the buy activities and this was considered more desirable than having more sensitive buy activities than might be expected for actual dairies.

Because of the preceeding, the results of the FOG concentration limitation are not realistic and one of the changes made should be incorporated into the model and new solutions obtained. However, the extremes to which the optimization took the Case Study Plant, indicate the severity of such effluent restrictions on a dairy plant. The authors believe that dairies now exist under such restrictions only because of the inaction of the municipal regulatory agents. The authors found the situation described above in all FOG solutions except CASESTYW and

CASESTYO.

Limitations of the Model

The model is first limited by the analysis method chosen. Even though LP is a very powerful tool for management to consider alternative approaches to water and waste reductions, the inherent limitations of LP must not be forgotten. First and foremost, the use of LP requires a linear equation for each particular combination of activities. Real world dairies would not always have linear relationships.

Next, the formulation of objective function costs (c_j values) often requires assumptions that may not be valid. For example, the objective function cost coefficient for the series of collection tank related activities was assumed by taking the increased cost of the entire system and dividing the cost by the maximum total amount expected through the collection system. If less than the maximum amount goes through any of the seven components of the system, the costs would be understated. However, when an optimal solution is reached and closer approximations of costs are needed, the cost coefficient for these activities could be recalculated using the actual amount through the system. Then, the model could be rerun given a more realistic objective function value.

The greatest limitation of the model was the unavailability of literature or plant data to formulate the activity transfer coefficients (a_{ij} values) for the water and waste related activities. The coefficients were estimated for the Case Study Plant using the best information available. The incorporation of this model into an analysis of an actual dairy would afford the user the opportunity to secure the needed information to develop the coefficients. However, the authors doubt the value of securing exact coefficients for each water and waste related activity. A more productive approach in this authors' opinion would be to use the best estimates available modified with plant observations to effect a solution(s) of the model. Then the more critical activities in terms of costs should be selected for detailed observations to obtain hard data to reformulate the coefficients. Then the model could be rerun to determine the effect of the new coefficients. This process could be repeated until the desired results are obtained.

A real limitation of the model as presented was the difficulty of individual incorporation of any activities that affect all or many of the activities presented. Examples include CIP systems, COP systems and hose station uses. These activities could be individually incorporated into the model only with a considerable model expansion. They now are incorporated into the model as an integral part of each activity using them.

Finally, the use of the model by a real world dairy may be more than the average dairy plant manager can accomplish. A person skilled in the use of LP would be needed to help the manager formulate the model for his plant. However, after the model has been formulated, the author believes that almost any dairy manager could obtain useful information using such a model.

Increased water use for the process alternatives was not reflected in the water or sewer activity coefficients as the cost of the increased water and sewer was shown as an increased cost reflected in the c_j for the process change. Thus, water use activity was slightly smaller than estimated, but the objective function value and solution were not affected.

A simplified model, utilized coefficients for departments or the whole plant, while less useful than the full model, may be a useful tool for operating dairy plants.

Difficulties Encountered in Model Formulation

The authors found the development of the LP model a challenging and formidable task. The incorporation of selected data from a number of plants into the Case Study Plant was difficult and time consuming. The estimation of activity transfer coefficients was more difficult than the authors had assumed. Most dairy plants were found not to have the needed information to develop these coefficients. The selection of activities to be included in the model was difficult. Frequent definitional changes of the activities required reformulation of the activities.

Consistency of the sign convention for the transfer coefficients was a real problem. Making all supply transfers negative helped to eliminate much of the authors' early confusion with signs during the initial formulation of the model.

No one book exists to help the new initiate in LP formulations. Many books talk about the formulation of LP problems. However, they usually forget to explain that the modeling procedure is much more difficult than explained. Also, the authors usually ignore the art of LP modeling and place emphasis on the scientific aspects and mathematical solutions. These authors found that it took months of playing with the model before the sense was developed to effectively model the Case Study Plant.

The model developed sought to minimize the objective function. Subsequently, any activity with a negative cost coefficient must be bounded or the optimization procedure used will allow the activity to increase to infinity giving an unbounded solution. This was encountered with the animal feed selling activity and was eliminated using an equality transfer from the collection tank.

SUMMARY AND CONCLUSIONS

The Case Study Plant was developed and the details have been presented. The analysis of the overall coefficients for the plant product areas indicated that Management Action for the control of water and waste was both vital and profitable in the Case Study Plant. A net savings per year of $433,184 was estimated for the Management Action reductions of water and waste with increased costs of only $51,374/yr. Water savings were approximately 36,000,000 gal/yr and the estimated BOD reduction was over 500,000 lb/yr.

Operational water and waste related parameters were tabulated for each key process in the production sequence of the Case Study Plant. The development of this information may prove useful in future studies as they are more complete than those available in the literature.

The linear analysis model was developed and was proven useful for analyzing water and waste related activities in the Case Study Plant. Only relatively minor changes would be required to extend the usefulness of the model to actual dairy plant. The procedure of using the Case Study Plant model with the linear programming algorithm was shown useful for examining the increasing cost of water, the increasing cost of sewer and effluent limitations similar to those found in municipal sewer use ordinances. The model was useful in determining the benefits of process alternatives. The usefulness of the linear analysis procedure was shown and after modifications suggested should be of benefit to dairy plant management, governmental policy makers, equipment manufacturers and planners.

However, many of the techniques of model formulation and operation require a reasonable degree of skill obtained through considerable experience. Thus, the use of the LP approach for management as a design tool is beyond the experience of most dairy plant managers and most municipal city engineers. A formulation specialist would be needed to successfully adapt the model for use. This would necessitate the specialist becoming familiar with the dairy plant and the manager or engineer understanding the capabilities and limitations of the specialist.

Zero discharge of the waste load parameters (BOD, FOG) were proven infeasible for the Case Study Plant as levels of 2000 mg/l for BOD and 250 mg/l for FOG were found to negate much of desired products production. Processes with greatly reduced water use and waste loads would be needed and much more sophisticated product recovery systems before minimal discharge of pollutants could be achieved in the Case Study Plant. As the authors utilized most of the more important technological process alternatives, they conclude that dairy plants can not meet effluent restrictions with the current technologies available.

The dairy industry must become more familiar with the effect of BOD and FOG limitations on their operations. The results of the LP analysis indicate that even the least stringent of effluent limitations found in the average sewer use ordinance prohibits the production of some products. The enforcement of these sewer use restrictions would have a dramatic effect on the dairy industry. The authors concluded based on industry observations, that the reason the dairy industry has not experienced these effects is because most municipalities are not yet enforcing their sewer use ordinances.

An important aspect of the reduction of the waste and hydraulic loading of the Case Study Plant not incorporated into the model were the reduced costs of pretreatment and/or treatment facilities either for the plant or the municipality that would be incurred as a result of the changes. The authors believe that cost minimization of wastewater should not only be a plant goal but a goal for society. Regardless of who builds and runs treatment facilities, costs of new facilities will be almost proportionately reduced by hydraulic and waste reductions and operating costs will also be lowered.

RECOMMENDATIONS

A. The implementation of the use of linear programming techniques and computer solutions of the linear analysis model is feasible and should provide a better basis for assessing management action in the future with respect to water and wastewater control.

B. The use of the model for an actual dairy should proceed as follows:

1. The following information should be acquired:
   a. Cost coefficients
   b. Process flow charts
   c. Gross water use and wastewater discharge
   d. Gross wastewater characterization
2. An experienced LP formulator should become familiar with the plant and incorporate the plant specifics into the model.
3. Solutions should be obtained to establish the validity of the model.
4. Management should suggest variables for analysis.
5. Results should be used to help formulate plant policy and expenditures.

C. The results have shown that dairy plants are very sensitive to effluent limitations on BOD and FOG. The dairy industry should relate this information to the following.

1. Municipal officials in charge of the development and enforcement of sewer use ordinances.
2. State and Federal officials (EPA) who require and

supervise sewer use ordinances.

3. Federal legislators and regulatory officials (EPA) who are responsible for "zero discharge" goal of PL 92-500.

4. Researchers to help develp processing techniques to help eliminate BOD and FOG from dairy wastewaters.

D. The linear program model can be a powerful tool for future research in determining optimal methods for reducing water discharges by food plants. The authors would recommend the model for futher similar studies as now that the model is formulated, a researcher can more easily use the model and computer solutions than the tedious hand calculation procedures.

E. The water and waste coefficients developed in the course of preparing this document represent the most complete compilation available in the literature and form the basis for estimation of expected losses in fluid milk, ice cream and cottage cheese manufacturing plants. Research is needed to confirm the validity of these estimated coefficients.

F. Questions raised in this investigation with regard to the legality of the use of recovered dairy products and product-water mixtures need to be resolved. The utilization of recovery schemes was shown to be economically dependent on the use of the recovered material.

APPENDIX

User's Manual for the Dairy Process Model

Introduction

This user's manual will describe the use of a linear model of dairy processing which was developed as an aid to studying the economic impact of municipal sewer discharge regulations on the dairy industry. Presented in this manual is a brief description of the model and its solution algorithm, details of data input, techniques for model operation, plus an example of model use illustrating the way policy evaluations are executed. This manuals was developed, in part, from a similar manual completed by Calloway (1974) for the dairy industry by Carawan (1977).

Model Description

The model presented in a linear programming (LP) model of a large multiproduct dairy processing plant. The modeled complex is assumed to be of new construction or a major renovation of an existing facility. The model contains all the necessary facilities such as garage, steam generating, refrigeration and needed management and sales complex. The model contains all the necessary facilities to treat and/or dispose of all waste streams generated in production processes or the ancillary processes. An array of alternatives is provided for each function to allow plant configuration to adapt to changes in operating conditions, product mix and/or effluent discharge restrictions.

The model may be used to evaluate water use, wastewater discharge, product mix and cost effects of (1) increasingly restrictive effluent limitations, (2) increasingly higher prices for water withdrawals, (3) increasingly higher prices for sewer discharge, (4) increasingly higher prices for surcharges, (5) technological improvements in production processes, (6) changes in price or supply of raw materials and (7) changes in availability or demand for finished products.

Items (1), (2), (3), (4), (6) and (7) can be easily performed using the model in its present configuration. The technology matrix must be expanded by one or more columns for each added process to be evaluated.

Each solution of the model: (1) identifies an optimal configuration consisting of the production facility, the waste treatment control or treatment system and the product mix, (2) gives the least-cost levels of operation for each production and treatment process, (3) indicates the marginal costs of any resource of effluent restrictions and (4) gives the total cost of dairy production, water use and wastewater treatment.

For each waste parameter to be considered, the effluent standard may be systematically decreased to include zero discharge. Similarly, the price of water withdrawals and sewer discharges may be systematically increased to investigate possible changes in water-use patterns, wastewater discharge patterns and the product cost effects of these higher prices. Also, the same procedure could be repeated for increasing prices of surcharges.

<u>Algorithm Description</u>

The dairy model was a linear programming model comprized of approximately 150 columns and 150 rows. The model was run using International Business Machines Corporation (IBM 370/165) computer using the Mathematical Programming System (MPS)/360 (360A-CO-14X) version 2. The use of LP and the MPS/360 package is described in IBM manuals (IBM, 1964; IBM, 1969a; IBM 1970a; IBM, 1969b; IBM, 1970b; IBM, 1968; IBM, 1969c). The data input format is completely described in the IBM manuals and will be briefly described in the next sections. Specific adaptations of the MPS/360 package are detailed by McAllister (1973).

Data Input

The model is available on computer cards as a data matrix. The data matrix for the dairy model immediately preceded this User's Manual. Included is a description of all rows (Table 53) and columns (Table 54).

The data matrix is separated into three parts: (a) rows identification (ROWS), (b) columns description (COLUMNS), and (c) right hand side specifications (RHS). Each row in the data matrix is a linear equation which represents either a resource restraint, a material balance or some manipulative function within the model. In the ROWS section, each row is identified and designed as an equality (E), greater than or equal (G), less than or equal (L), or free (N) objective function row. In the COLUMNS section, each model activity is described in terms of the proper input and output of the resources listed in the ROWS section. The RHS section is a single column vector which contains information regarding limitations on resources available to the model. The restrictions used are displayed in Table 55.

Table 53. Description of Vectors (Rows) for CASESTUD

TYPE	ROW NAME	DESCRIPTION	UNIT
L	MAXFOG	FOG transfer	lb
L	MAXBOD	BOD transfer	lb
L	GOODRTTR	Good return transfer	lb
L	COLLTR	Transfer from COLLECT	lb
L	RECRHTR	Transfer from HISOLID	lb
L	BADRTTR	Bad return transfer	lb
L	DRIPTRIC	Drip collection transfer from ice cream	lb
L	RHTRFM	Fluid filler recovery transfer	lb
L	DRIPTRFM	Fluid filler drip transfer	lb
L	RMRCBTR	Clarifier sludge recovery transfer	lb
L	WHEYTR	Whey transfer	lb
L	REMELT	Remelt transfer	lb
L	FMHTASTR	HTST recovery transfer	lb
N	OBJ	Objective function	$
G	LOSSTRIC	Ice cream loss transfer	lb
L	BLTRIC	Ice cream transfer from blend	lb
L	HTTRIC	Ice cream transfer from HTST	lb
L	SPTRIC	Ice cream transfer from surge	lb
L	TRMTRIC	Ice cream transfer from pumping	lb
L	FNTRIC	Ice cream transfer from feeder	lb
L	AFTRIC	Ice cream transfer from freezer	lb
L	TRFTRIC	Ice cream transfer from pumping	lb
L	FFTRIC	Filled ice cream transfer	lb
L	STORIC	Ice cream transfer to storage	lb
L	FNTR	Fruit and nut transfer	lb
L	MAXWHSIC	Whey solids restriction for ice cream	lb
L	MAXIC	Product restriction for ice cream	1000 lb
G	MINIC	Product restriction for ice cream	1000 lb
L	MAXBPIC	Buttermilk powder restriction for ice cream	lb
E	WEIGHTIC	Ice cream blend transfer	lb
E	ICTR	Ice cream transfer	lb
L	MAXLACIC	Lactose restriction for ice cream	lb
L	MAXCRNIC	Corn syrup solids restriction for ice cream	lb
L	MAXTSIC	Solids restriction for ice cream	lb
G	MINSUG1	Sugar restriction for ice cream	lb
G	MINSBIC	Stabilizer restriction for ice cream	lb
G	MINMSNF1	Solids restriction for ice cream	lb
G	MINMFIC	Fat restriction for ice cream	lb
L	STOREOJ	Orange juice transfer to storage	lb
L	FFTROJ	Orange juice transfer from filling	lb
L	VCTROJ	Orange juice transfer from vat cooling	lb
L	BLTROJ	Orange juice transfer from blend	lb

Table 53. continued

TYPE	ROW NAME	DESCRIPTION	UNIT
E	WTOJ	Orange juice blend transfer	lb
G	MINOC	Orange juice concentrate restriction	lb
L	MAXOC	Orange juice concentrate restriction	lb
G	MINOJ	Orange juice production restriction	1000 lb
L	MAXOJ	Orange juice production restriction	1000 lb
L	MAXFCFA	Fruit Concentrate restriction	lb
L	MAXLSFA	Sugar restriction	lb
G	MINFCFA	Fruit concentrate restriction	lb
G	MINLSFA	Sugar restriction	lb
E	WTFA	Fruitade bland transfer	lb
L	BLTRFA	Fruitade transfer from blend	lb
L	VCTRFA	Fruitade transfer from vat cooling	lb
L	STOREFA	Fruitade transfer to storage	lb
L	MAXFA	Fruitade production restriction	1000 lb
G	MINFA	Fruitade production restriction	1000 lb
E	FOGTR	FOG transfer	lb
E	BOD5	BOD_5 transfer	lb
E	SEWERTR	Sanitary sewer transfer	gal
G	LOSSTRFM	Fluid milk loss transfer	lb
G	LOSSTRRM	Raw milk loss transfer	lb
L	MAXSUGFM	Sugar restriction for fluid milk	lb
G	MINSUGFM	Sugar restriction for fluid milk	lb
L	MAXBFFM	Fat restriction for fluid milk	lb
G	MINBFFM	Fat restriction for fluid milk	lb
L	MAXMSFM	Milk solids restriction for fluid milk	lb
G	MINMSFM	Milk solids restriction for fluid milk	lb
L	MAXCAFM	Chocolate additive restriction for fluid milk	lb
G	MINCAFM	Chocolate additive restriction for fluid milk	lb
E	MIXFM	Fluid milk blend transfer	lb
L	BLTRFM	Fluid milk transfer from blend	lb
L	HTTRFM	Fluid milk transfer from HTST	lb
L	SPTRFM	Fluid milk transfer from surge	lb
L	FFTRFM	Fluid milk transfer from filling	lb
L	STORFM	Fluid milk transfer to storage	lb
L	FMTOT	Fluid milk transfer	lb
G	MINFM	Fluid milk production restriction	1000 lb
L	MAXFM	Fluid milk production restriction	1000 lb
L	MAXSBSC	Sterilizer restriction from sour cream	lb
E	MIXSC	Sour cream blend transfer	lb
L	BLTRSC	Sour cream transfer from blend	lb
L	TRTRSC	Sour cream transfer from pumping	lb

Table 53. continued

TYPE	ROW NAME	DESCRIPTION	UNIT
L	CUTRSC	Sour cream transfer from culture	lb
L	VPTRSC	Sour cream transfer from vat pasteurization	lb
L	HOTRSC	Sour cream transfer from homogenization	lb
L	FFTRSC	Sour cream transfer from filling	lb
L	STORSC	Sour cream transfer to storage	lb
G	MINSTSC	Starter restriction for sour cream	lb
E	WTSC	Blend transfer for sour cream	lb
L	MAXSNFSC	Solids restriction for sour cream	lb
G	MINSNFSC	Solids restriction for sour cream	lb
G	MINSBSC	Stabilizer restriction for sour cream	lb
G	MINFSC	Fat restriction for sour cream	lb
G	MINFSC1	Fat restriction for sour cream	lb
G	MINSC	Sour cream production restriction	1000 lb
L	MAXSC	Sour cream production restriction	1000 lb
G	MINBM	Buttermilk production restriction	1000 lb
E	MIXBM	Buttermilk blend restriction	lb
G	MINSTBM	Starter restriction for buttermilk culture	lb
L	MAXSTBM	Starter restriction for buttermilk culture	lb
G	MINFBM	Fat restriction for buttermilk culture	lb
E	BLTRBM	Buttermilk transfer from blend	lb
E	WTBM	Buttermilk blend transfer	lb
L	MAXBM	Buttermilk production restriction	1000 lb
E	FFTRBM	Buttermilk transfer from filling	lb
E	TRTRBM	Buttermilk transfer from pumping	lb
E	VCTRBM	Buttermilk transfer from vat cooling	lb
E	CUTRBM	Buttermilk transfer from culture	lb
E	STORBM	Buttermilk transfer from conveying	lb
E	RCTRRM	Raw milk transfer from receiving	lb
L	PRTRCM	Cream transfer from separation	lb
L	PRTRSM	Skim transfer from separation	lb
E	TOTPRODT	Total products transfer	lb
G	SSEWTR	Sanitary sewer transfer	lb
L	POTWATER	Potable water transfer	gal
G	LOSSTRCC	Cottage cheese loss transfer	lb
E	TPTR	Total products transfer	lb
L	STABIL	Stabilizer transfer	lb
L	SKIM	Skim transfer	lb
L	RAWMILK	Raw milk transfer	lb
L	ORANGEC	Orange concentrate transfer	lb

Table 53. continued

TYPE	ROW NAME	DESCRIPTION	UNIT
L	LCORNSUG	Corn syrup transfer	lb
L	LCANESUG	Sugar transfer	lb
L	INGRED	Ingredient transfer	lb
L	FRUITCON	Fruitade concentrate transfer	lb
L	CREAM	Cream transfer	lb
L	CONDSKM	Condensed skim transfer	lb
L	CHOCING	Chocolate ingredient transfer	lb
L	BUTTOIL	Butteroil transfer	lb
L	BUTMPOWD	Buttermilk powder transfer	lb
L	FRUITNUT	Fruit and nut transfer	lb
L	CCMAXFDS	Fat restriction for dressing	lb
G	CCMINFDS	Fat restriction for dressing	lb
G	CMINTSDS	Solids restriction for dressing	lb
L	CMAXTSDS	Solids restriction for dressing	lb
E	CCWTDS	Dressing transfer	lb
L	MAXCC	Production restriction for cottage cheese	1000 lb
G	MINCC	Production restriction for cottage cheese	1000 lb
L	CCBYTR	Buy cottage cheese transfer	lb
L	STORCC	Filled cottage cheese transfer to storage	lb
L	MAXFCC	Fat refrigeration for cottage cheese	lb
G	MINFCC	Fat restriction for cottage cheese	lb
E	WTCC	Equality restriction for cottage cheese	lb
G	CCMINST	Starter restriction	lb
L	CCMAXST	Starter restriction	lb
E	CCSET	Culture transfer	lb
L	YIELDCC	Curd yield transfer	lb
L	WATRCC	Curd transfer from washing	lb
L	BLTRCC	Cottage cheese transfer from blend	lb

Table 54. Description of Vectors for Basic Solution (Columns) (CASESTUD).

Code	Activity	Unit of Activity
BUYWAT	Potable water buying and supplying for use	lb
RMRC	Raw milk receiving	lb
RMPR	Raw milk separating	lb
RMUS	Raw milk use	lb
SMUS	Skim milk use	lb
CMUS	Cream use	lb
WHUS	Whey use	lb
CSUS	Condensed skim use	lb
LCUS	Liquid corn syrup use	lb
LSUS	Liquid cane sugar use	lb
FCUS	Fruitade concentrate use	lb
SBUS	Stabilizer use	lb
OCUS	Orange juice concentrate use	lb
IGUS	Ingredients use	lb
CAUS	Chocolate based additive use	lb
BPUS	Buttermilk powder use	lb
BOUS	Butteroil use	lb
REUS	Ice cream remelt use	lb
TOTPRODS	Total products processed	lb
SURCHB	Paying for BOD_5 in effluent	lb
FOG	Accumulation of fats, oils and greases lost during processing	lb
STORMSEW	Discharge of effluents to storm sewer	gal
SANSEWER	Discharge of products and process water to sanitary sewer	gal
CCCMUS	Use of cream for preparation of cottage cheese dressing	lb
CCST	Preparation for use of cottage cheese starter	lbs
CCHT	Pasteurization of skim for cottage cheese by HTST	lb
CCCU	Process processing skim milk into cottage cheese curd	lb
CCWA	Process of draining the whey, washing the cottage cheese curd and fines loss	lb
CCVC	Cooling of cottage cheese curd	lb
CCBL	Blending of cottage cheese curd and dressing	lb
CC	Creamed cottage cheese	lb
CCDS	Blending of cottage cheese dressing	lb
CCFF	Filling of creamed cottage cheese	lb

Table 54. continued

Code	Activity	Unit of Activity
CCSF	Storage of filled cottage cheese containers	lb
DSSMUS	Skim milk use for cottage cheese dressing	lb
BMSMUS	Skim milk use in buttermilk	lb
BMCMUS	Cream use in buttermilk	lb
BMBL	Blending of buttermilk ingredients	lb
BMST	Production of buttermilk starter	lb
BMVP	Vat pasteurization of milk for buttermilk	lb
BMCU	Culturing skim and starter to make buttermilk	lb
BMVC	Vat cooling of buttermilk	lb
BMTR	Transfer of buttermilk from vat to fillers	lb
BMFF	Filling of buttermilk	lb
BMCV	Conveying, casing and stacking of buttermilk containers	lb
BMSF	Storage of cased buttermilk in cooler	lb
FMILK	Fluid milk products	lb
BUYFM	Buying of cartoned fluid milk products	lb
FMSMUS	Skim milk use for fluid milk products	lb
FMCMUS	Cream use for fluid milk products	lb
FMBL	Blend for fluid milk products	lb
FMHT	HTST pasteurization of fluid milk products	lb
FMSP	Pasteurized storage of fluid milk products	lb
FMFF	Filling of fluid milk products	lb
FMCAUS	Chocolate additive use for fluid milk products	lb
FMCSUS	Condensed skim use for fluid milk products	lb
FMLCUS	Liquid corn syrup use for fluid milk products	lb
FMCV	Conveying, casing and stacking of filled fluid milk products	lb
FMSF	Storage of fluid milk products	lb
SCCMUS	Cream use for sour cream	lb
SCSMUS	Skim milk use for sour cream	lb
SCCSUS	Condensed skim use for sour cream	lb
SCSBUS	Stabilizer use for sour cream	lb
SCBL	Blending of sour cream ingredients	lb
SCVP	Vat pasteurization of sour cream mix	lb

Table 54. continued

Code	Activity	Unit of Activity
SCHO	Homogenization of sour cream mix	lb
SCVC	Vat cooling of sour cream mix	lb
SCCU	Culturing of sour cream mix	lb
SCST	Storage of sour cream	lb
SCTR	Pumping of sour cream to fillers	lb
SCFF	Filling of sour cream	lb
SCCV	Conveying sour cream including casing	lb
SCSF	Storage of sour cream in cooler	lb
FABL	Blending of concentrate, sugar and water to make fruitade	lb
FAVC	Vat cooling of fruitade	lb
FAFF	Filling of fruitade	lb
FASF	Storage in cooler of fruitade	lb
FACV	Conveying filled containers of fruitade through casers and stackers	lb
FAWPUS	Use of product water for dilution of fruitade concentrate	lb
FALSUS	Use of liquid sugar in fruitade	lb
FPFCUS	Use of fruitade concentrate in fluid milk processing	lb
FAFCUS	Use of fruitade concentrate in fruitade processing	lb
OJBL	Blending of orange juice concentrate and water in vat	lb
OJVC	Cooling of orange juice in vat	lb
OJFF	Filling of orange juice	lb
OJCV	Conveying filled containers through casers and stackers	lb
OJSF	Storage of orange juice	lb
OJWPUS	Potable water used for dilution of orange juice concentrate	lb
OJOCUS	Orange concentrate use for orange juice	lb
ICWPUS	Use of water for dilution of ice cream ingredients	lb
ICCMUS	Use of cream in ice cream	lb
ICSMUS	Use of skim milk in ice cream	lb
ICRMUS	Use of raw milk in ice cream	lb
ICWNUS	Use of neutralized whey in ice cream	lb
ICLSUS	Use of liquid cane in ice cream	lb
ICLCUS	Use of liquid corn syrup in ice cream	lb
ICCSUS	Use of condensed skim milk in ice cream	lb
ICSBUS	Use of stabilizer in ice cream	lb
ICBPUS	Use of buttermilk powder in ice cream	lb

Table 54. continued

Code	Activity	Unit of Activity
ICBOUS	Use of butteroil in ice cream	lb
RHUS	Use of recovered product-high solids for ice cream	lb
REUS	Use of ice cream remelt for ice cream	lb
ICBL	Blending of ice cream ingr nts in a vat	lb
ICHT	HTST processing of ice cream mix	lb
ICSP	Vat storage of ice cream for aging and flavoring	lb
ICAF	Partial freezing of ice cream in continuous freezers	lb
ICTRF	Transfer of frozen ice cream	lb
ICFN	Fruit, nuts and flavor addition to ice cream	lb
ICFF	Filling of ice cream	lb
ICZZ	Hardening of filled packages of ice cream in plate unit	lb
ICSF	Storage of ice cream in -20F frozen storage	lb
ICBY	Buying of ice cream	lb
IC	Ice cream	lb
OTHER	Ancillary activities for plant including offices, garage, refrigeration systems, air supply system, etc.	lb
	Change Activities	
FMFSB	Storing of filled fluid milk products with recovery of returns	lb
COLLECT	Collecting bad returns	lb
HISOLID	Recovering good returns	lb
COLL6	Collecting recovered materials	lb
ANIMF	Selling animal feed	lb
TRUCK	Transporting collections for disposal	lb
HISOL1	Recovering product from fluid milk recovery system	lb
HISOL2	Recovering product from HTST recovery system (FMHTAS)	lb
COLL1	Collecting whey	lb
COLL2	Collecting ice cream drips	lb
COLL3	Collecting fluid product filler drips	lb
COLL4	Collecting clarifier sludge "shoots"	lb
COLL5	Collecting remelt from remelt system	lb
ICAFB	Continuous freezing of ice cream mix with remelt recovery system	lb

Table 54. continued

Code	Activity	Unit of Activity
RMRCB	Recovering clarifier sludge for collection	lb
FMHTAS	Pasteurizing of fluid milk with recovery of start-up, shut-down and switch-over product-water mixtures	lb
OTHERD	Ancillary activities with all water saving alternatives included	lb
OTHERB	Ancillary activities with the installation of evaporative condenser	lb
OTHERC	Ancillary activities with process alternative for compressor cooling water recycle	lb
CCWAD	Draining and recovering whey, washing curd and recovery of fines with clarifier	lb
CCWAC	Draining whey, washing curd and recovering fines with clarifier	lb
CCWAB	Draining whey and washing curd with whey recovery	lb
FMFFE	Filling fluid milk with drip shields	lb
FMFFD	Filling fluid milk products with drip shields installed	lb
FMFFC	Filling fluid milk products with product recovery system installed	lb
ICFFB	Collecting product drips from ice cream fillers and filling ice cream	lb
FMFFB	Filling fluid milk with casewasher recycle installed	lb

The objective function was identified and cost coefficients used listed in Table 56. The objective function included those activities relating to water and waste including buying water (BUYWAT), discharging sewer (SANSEWER), paying BOD surcharge (SURCHB), activities related to product losses and the uses of raw materials.

Running Model

Card Deck. The card deck required for operation of the dairy model contains three sections. These sections are illustrated in Figure 17. The computer control cards or card deck used for this model have been listed in Table 57. These cards are unique to the hardware system being used and the sample computer control cards (job cards) will apply to all models (each unique data deck).

Algorithm control cards (control program) determine which of the available user options are to be activated for a specific run. They control such things as input format, output format, type of calculation to be performed, calculation sequence, etc. In number they may ranged from 2 to 100 or more, depending on the problem definition; output desired and the algorithm used (Calloway, 1974). The dairy model had a control program of 16 cards as listed in Table 58.

The NAME card identifies the data deck. The dairy model had for a name of the data deck DAIRYWAW. The problem name for the example is CASESTUD (Table 58). A single computer run can allow variations of the input data deck by assigning different problem names for each variation. Card format for the NAME card and

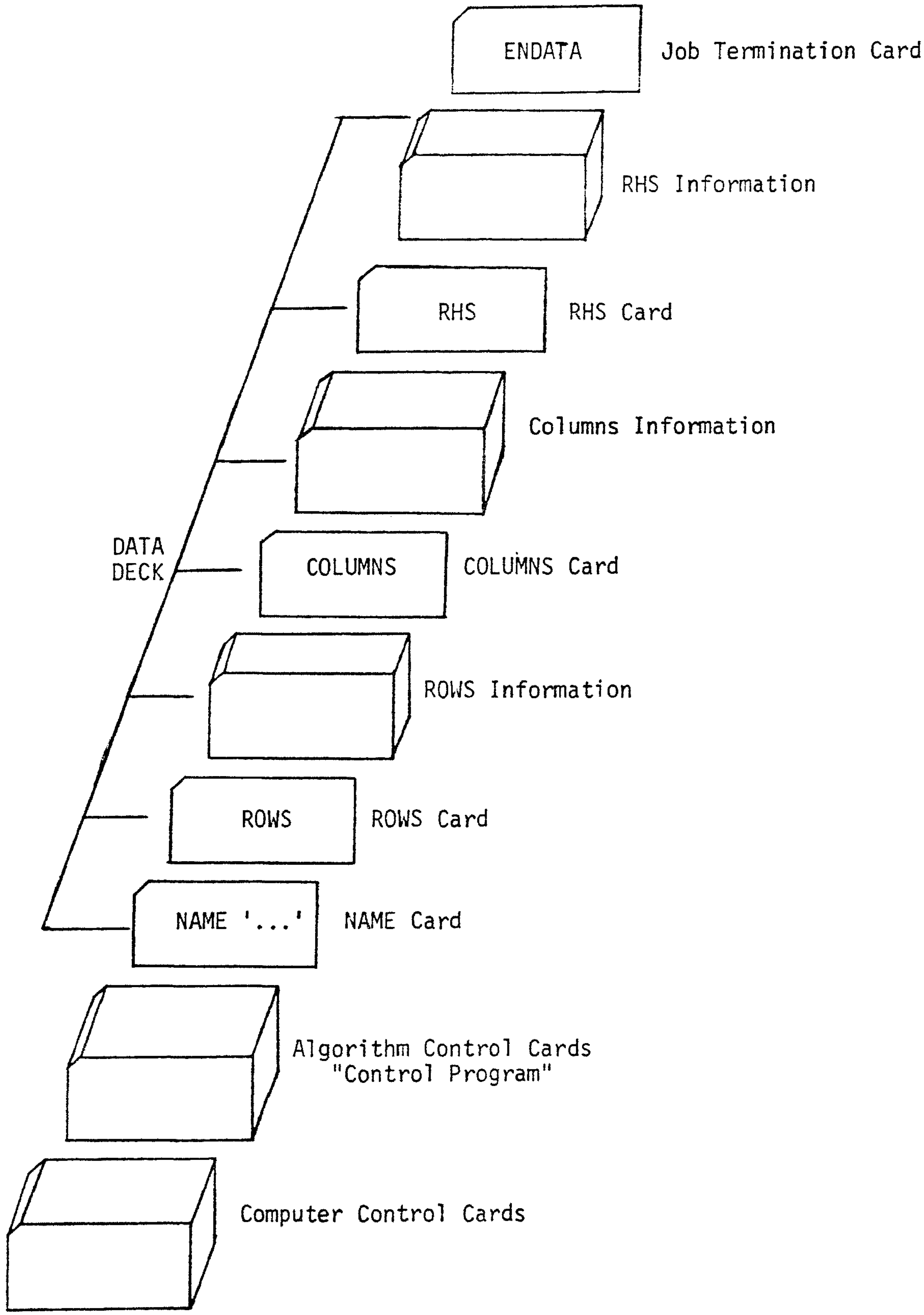


Figure 17. Card Deck Arrangement.

Table 55. Restrictions-Description of Vectors (RHS).

Code	Restriction	Units	Value
MINBM	Minimum buttermilk	1000 lb	4,500.
MAXBM	Maximum buttermilk	1000 lb	4,950.
MINCC	Minimum cottage cheese	1000 lb	1,500.
MAXCC	Maximum cottage cheese	1000 lb	1,650.
MINFA	Minimum fruitade	1000 lb	2,000.
MAXFA	Maximum fruitade	1000 lb	2,500.
MINFM	Minimum fluid milk	1000 lb	90,000.
MAXFM	Maximum fluid Milk	1000 lb	95,550.
MINIC	Minimum ice cream	1000 lb	5,000.
MAXIC	Maximum ice cream	1000 lb	5,500.
MINOJ	Minimum orange juice	1000 lb	750.
MAXOJ	Maximum orange juice	1000 lb	1,000.
MINSC	Minimum sour cream	1000 lb	500.
MAXSC	Maximum sour cream	1000 lb	550.

Table 56. Basic Objective Function Codes and Cost Coefficients.

Code	Activity Description	Units	Cost Coefficient ($/UNIT)
BUYWAT	Buying water for plant use	gal	V[a]
SANSEWER	Paying for sewer discharge	gal	0[b]
SURCHB	Paying for BOD5 discharge	lb	V[a]
ICLOSS	Paying labor, utilities, etc. (all costs except raw products) for the loss of ice cream from processing	lb	.05
CCLOSS	Paying labor, utilities, etc. (all costs except raw products) for the loss of cottage cheese from processing	lb	.15
FMLOSS	Paying labor, utilities, etc. (all costs except raw products) for the loss of fluid milk from processing	lb	.02
TRUCK	Transporting collected materials for disposal by truck	lb	.01
ANIMF	Selling collected materials as animal food	lb	-.01
RMUS	Supplying raw milk	lb	.11
SMUS	Supplying skim milk	lb	.055
CMUS	Supplying cream	lb	.366
CSUS	Supplying condensed skim	lb	.19
LCUS	Supplying liquid corn syrup	lb	.16
LSUS	Supplying liquid sugar	lb	.18
FCUS	Supplying fruitade concentrate	lb	.50
SBUS	Supplying stabilizer	lb	1.15
OCUS	Supplying orange juice concentrate	lb	.75
IGUS	Supplying ingredients	lb	.25
CAUS	Supplying chocolate additive	lb	.60
BUYFM	Purchasing of cartoned milk products	lb	.15
ICBY	Purchasing of cartoned ice cream	lb	.35
CCBY	Purchasing of cartoned cottage cheese	lb	.60
WHUS	Using whey for ice cream ingredient	lb	.01

[a]V = Varied [b]Included in BUYWAT cost coefficient

Table 57. Card Deck.

Card Deck Order
- Job Card -
// EXEC MPS
//CPC.SYSIN DD *
Control Program (Table 116) -
// EXEC.SYSIN DD *
- Data Input Cards -
NAME DAIRYWAW
ROWS
- Row Cards -
COLUMNS
- Column Cards -
RHS
- RHSI Cards -
ENDATA
/*

Table 58. Control Program (CASESTUD).

Control Program
PROGRAM
INITIALZ
MOVE (XDATA,'DAIRYWAW')
MOVE (XPBNAME, 'CASESTUD')
MOVE (XOBJ, 'OBJ')
MOVE (XRHS, 'RHSI')
CONVERT
BCDOUT
SETUP
PICTURE
TRANCOL
PRIMAL
SOLUTION
RANGE
EXIT
PEND

remainder of the data deck is as shown in Table 59.

Optional features such as placing upper and lower bounds on the level to which any activity (COLUMN) can exist in the vector solution (BOUNDS) were available but not used.

Optimal Solution. Calloway (1974) indicated that the simplest part of model operation is getting an optimal solution. This is only true when all the imputs are correct and there are no model flaws that prevent an optimal solution. Each specific algorithm differs in the detailed operations necessary to achieve an optimal solution. However, the basic steps are the same and were identified by Calloway (1974) as the following:

1. Identifying the problem to the computer.
2. Specifying where the objective function is to be maximized or minimized.
3. Selecting among output options.
4. Executing the algorithm.
5. Supplying the data matrix.

The solution output identifies the activities included in the solution set, the operating level of the activities and the marginal value of the resources used.

Policy Evaluation. Calloway (1974) used a procedure for policy evaluation of effluent policy somewhat similar to that used for this dairy model. Calloway called hs method variable resource programming which is the same as parametric analysis or sensitivity analysis. That is, after having obtained a basic optimal solution the RHS value of the resource (ROW) under study is systematically changed to reflect implementation of the

Table 59. Data Deck Card Format.

Column Number	Type Card	Card Entry
	NAME Card	
1		NAME
15-22		Name of Data Deck
	ROWS Card	
1		ROWS
	ROWS Identification Cards	
2		Inequality Specification
5-12		Row Identification
	COLUMNS Card	
1		COLUMNS
	COLUMNS Detail Cards	
5-12		Column Name
15-22		Row Name
25-36		Value
40-47		Row Name
50-61		Value
	RHS Card	
1		RHS
	RHS Detail Cards	
5-12		Right Hand Side Name
15-22		Row Name
25-36		Value
40-47		Row Name
50-61		Value

policy. In the dairy model case, the resource is biochemical oxygen demand (BOD) - (MAXBOD) of fats, oils and greases (FOG) - (MAXFOG). The model is initially formulated so that there are no restrictions on the discharge of BOD to the municipal sewer system and an initial optimal solution is obtained. The right hand side value of the resource row MAXBOD and/or MAXFOG is then systematically reduced from some larger value to some smaller value.

Each time the plant configuration changes because of a more restrictive effluent discharge policy, a new solution output is printed. If the values of the RHS for row MAXBOD is recorded for each change in the solution vector and plotted against the corresponding marginal value of biochemical oxygen demand, the result is a demand curve for waste disposal rights to the sewer under increasingly restrictive effluent policies. Similar curves can be developed for each waste in the model.

Conducting similar analyses on activity prices in the cost row (objective function) results in demand curves for the processes. Demand curves for water withdrawals (BUYWAT) and BOD surcharges (SURCHB) and sewer discharge are common applications of variable price programming.

Model Changes. Each column activity stands alone, independent of all others, except where two activities are required to satisfy a material balance equation which is true for a number of columns in the dairy model. In other words, if an activity requires a resource input, there must exist a complimentary activity which supplies the resource. Observing this one restriction, activities may be added to or deleted from the model at will. The same holds true for rows.

Output. The solution output from an LP algorithm contains several standard items. These include:

1. STATUS: optimal, feasible, infeasible, unbounded or no feasible solution.
2. Value of objective function.
3. Activities in solution.
4. Activity level of the vectors.
5. Marginal value of the resource.

Other information available depends on the algorithm and the user specified options.

There are a number of printout options as well. These are too varied to enumerate but two were used with the dairy model. One was to print the representation of the columns in terms of the current basis (TRANCOL). The other was the option to print a "picture", or computer representation of the data matrix (PICTURE). Figure 18 illustrates the picture option for the solution CASESTUD.

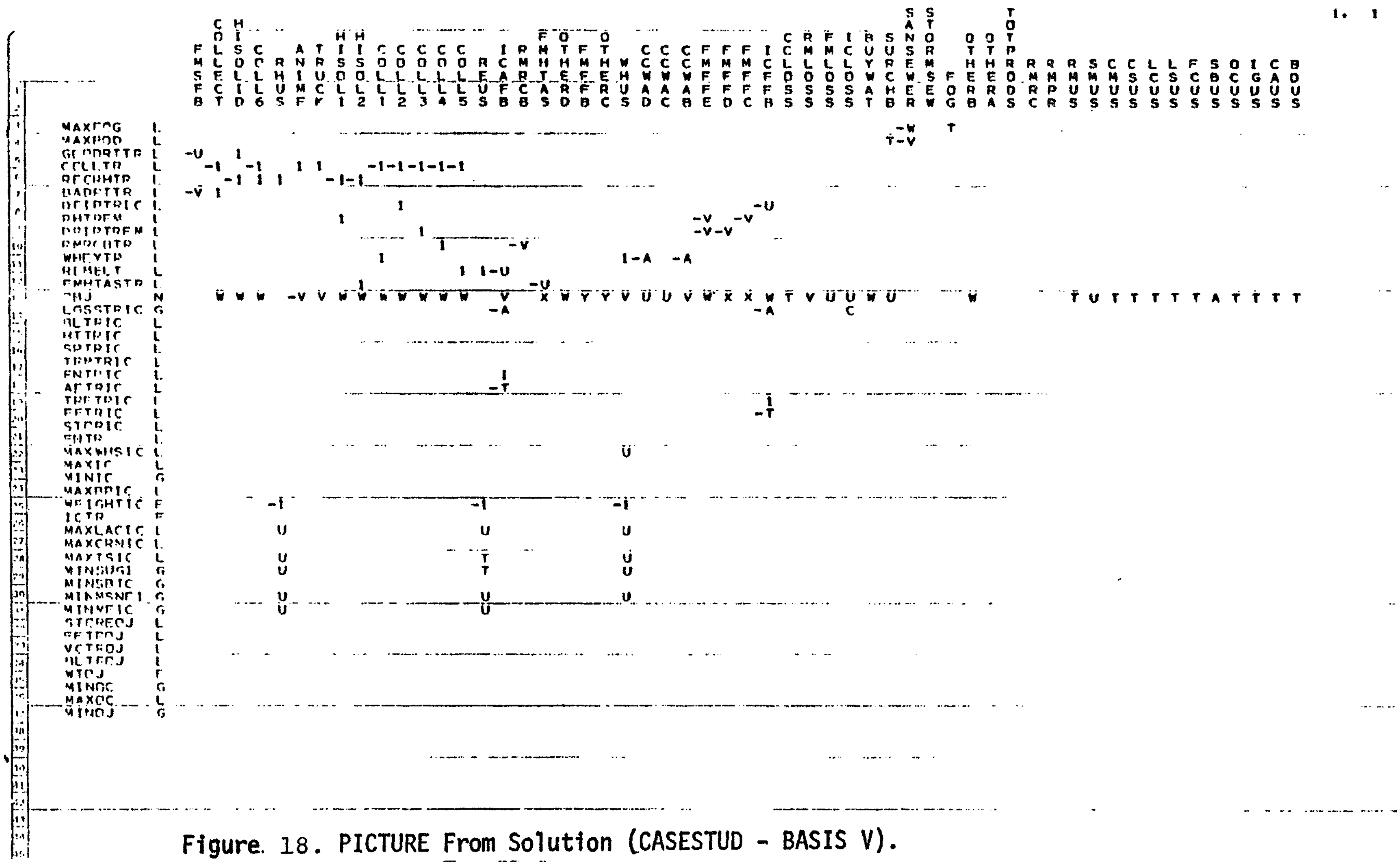


Figure 18. PICTURE From Solution (CASESTUD - BASIS V).

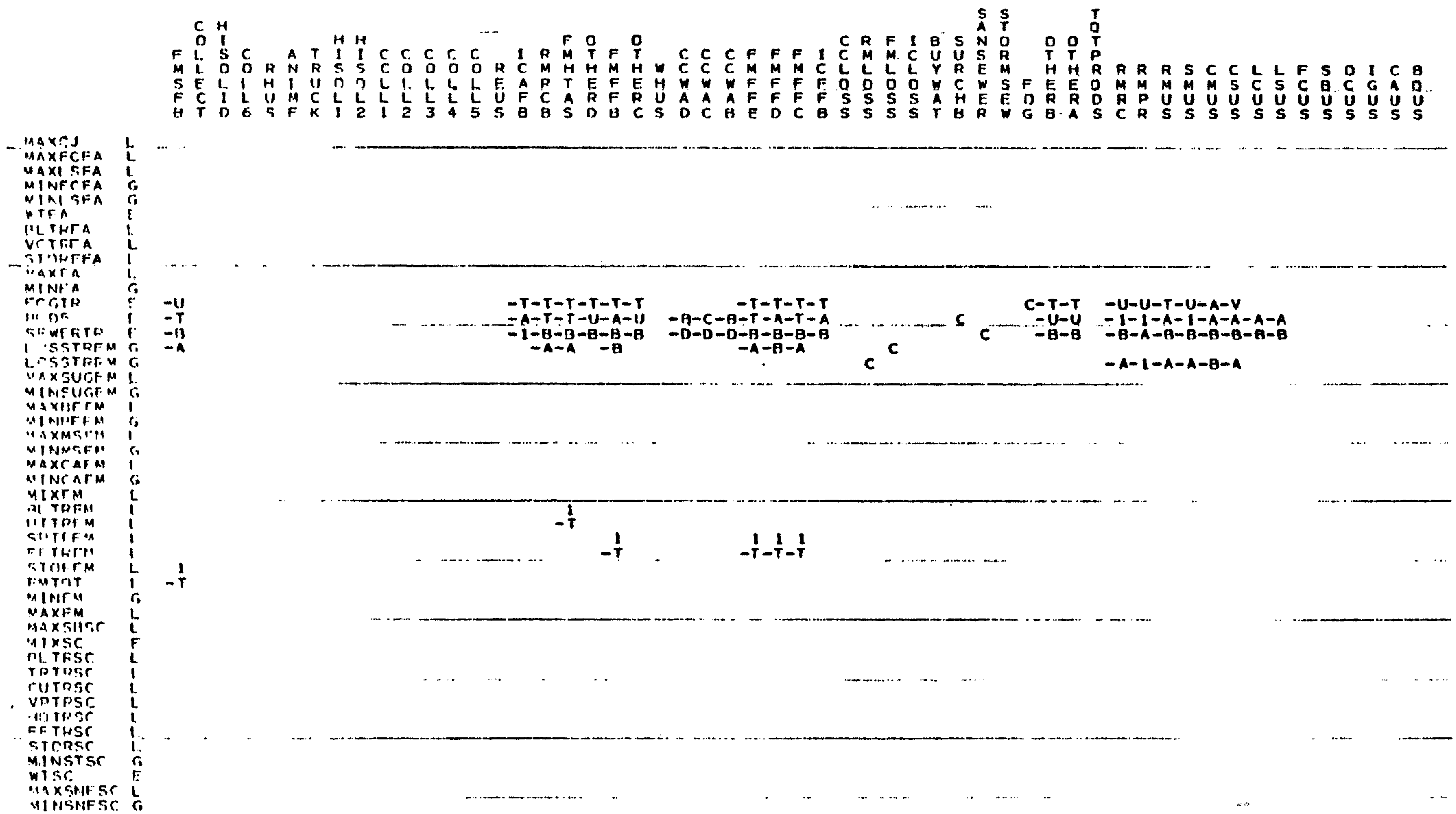


Figure 18. continued

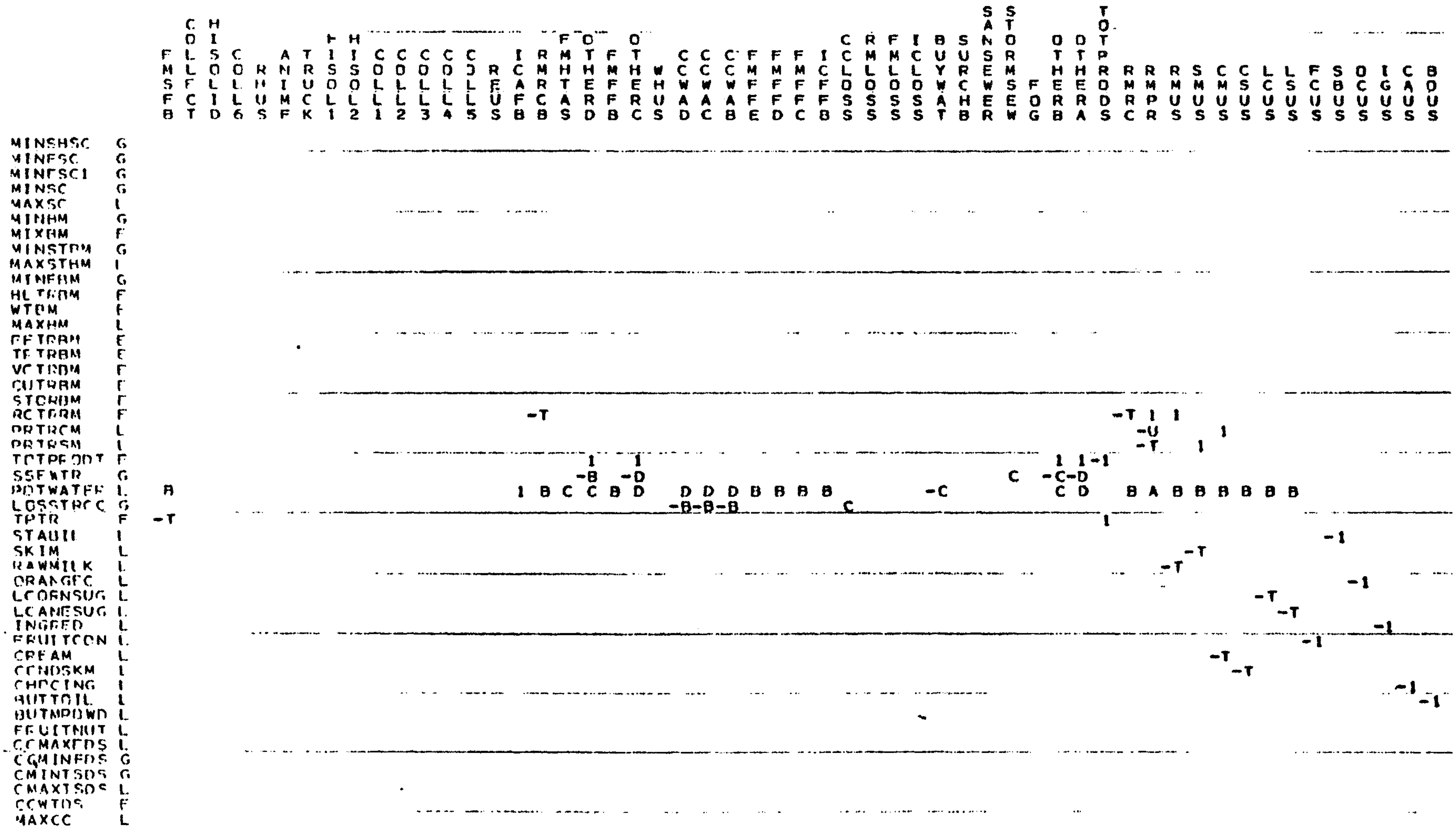


Figure 18. continued

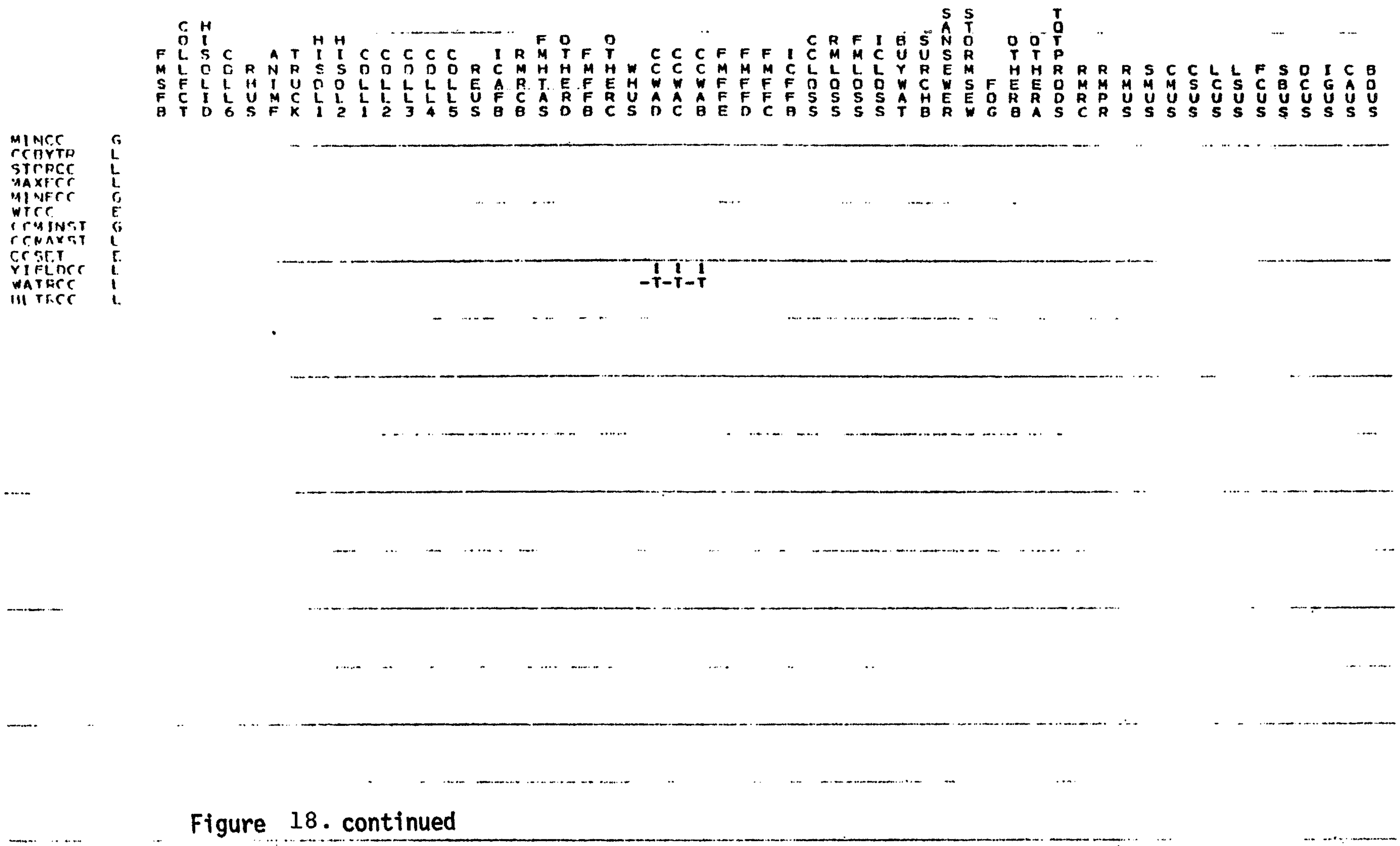


Figure 18. continued

		BPUS	FNUS	CCST	CCHT	CCCU	CCWA	CCVC	CCBL	CCFF	CCSF	CC	CCBY	CCDS	DSSMUS	CCCMUS	SCCMUS	SCSMUS	SCCSUS	SCSBUS	SCBL	SCVP	SCHD	SCVC	SCCU	SCST	SCTR	SCFF	SCCV	SCSF	BMSMUS	BMCMUS	BMBL	BMST	BMVP	BMCU	BMVC	BMTR	BMFF	BMCV	BMSF	FMCAUS	FMCSUS	FMCMUS	FMLCUS	FMSMUS	FMBL	FMHT	FMSP	FMFF	FMCV	FMSF	FMILK	BUYFM	FAFCUS	FAWPUS
MAXFOG	L																																																							
MAXPCD	L																																																							
GOOPRTTR	L																																																							
CELLTR	L																																																							
RECHUTR	L																																																							
BADRTTR	L																																																							
DRIPTRIC	L																																																							
RHTREM	L																																																							
DRIPTREM	L																																																							
RMECHTR	L																																																							
WHEYTR	L																																																							
REMELT	L																																																							
EMUTASTR	L																																																							
OBJ	N	U	T										T																																								T		
LOSSTRIC	G																																																							
BLTRIC	L																																																							
HTTRIC	L																																																							
SPTRIC	L																																																							
TRMTRIC	L																																																							
FNTRIC	L																																																							
AFTRIC	L																																																							
THETRIC	L																																																							
FFTRIC	L																																																							
STORIC	L																																																							
FNTP	L																																																							
MAXWHSIC	L																																																							
MAXIC	L																																																							
MINIC	G																																																							
MAXHPIC	L																																																							
WEIGHTIC	E																																																							
ICTR	E																																																							
MAXLACIC	L																																																							
MAXCRUIC	L																																																							
MAXTSIC	L																																																							
MINSUGI	G																																																							
MINSOIC	G																																																							
MINMSNFI	G																																																							
MINMFIC	G																																																							
STOREOJ	L																																																							
FFTROJ	L																																																							
VCTROJ	L																																																							
BLTROJ	L																																																							
WTOJ	E																																																							
MINOC	G																																																							
MAXOC	L																																																							
MINOJ	G																																																							

Figure 18. continued

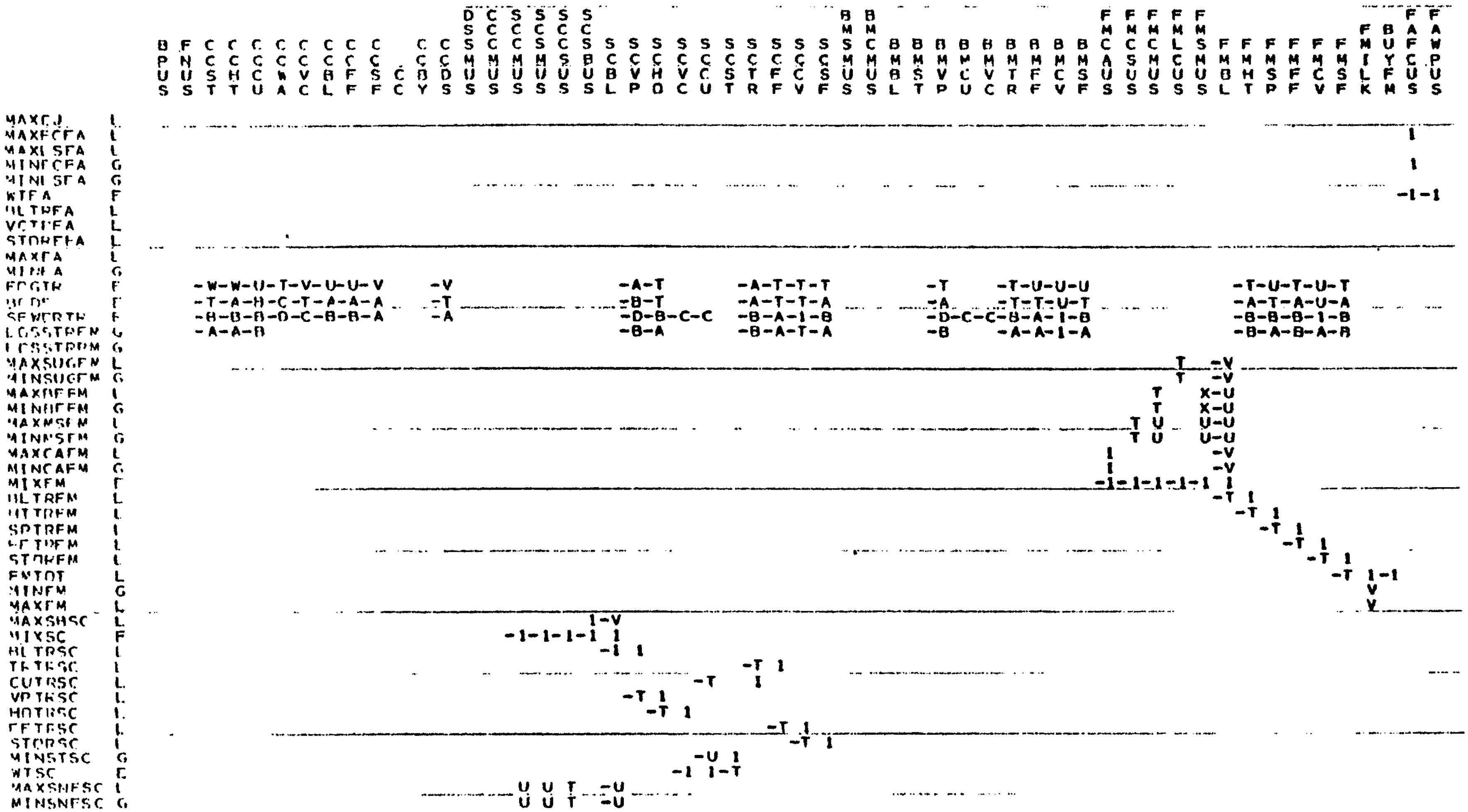


Figure 18. continued

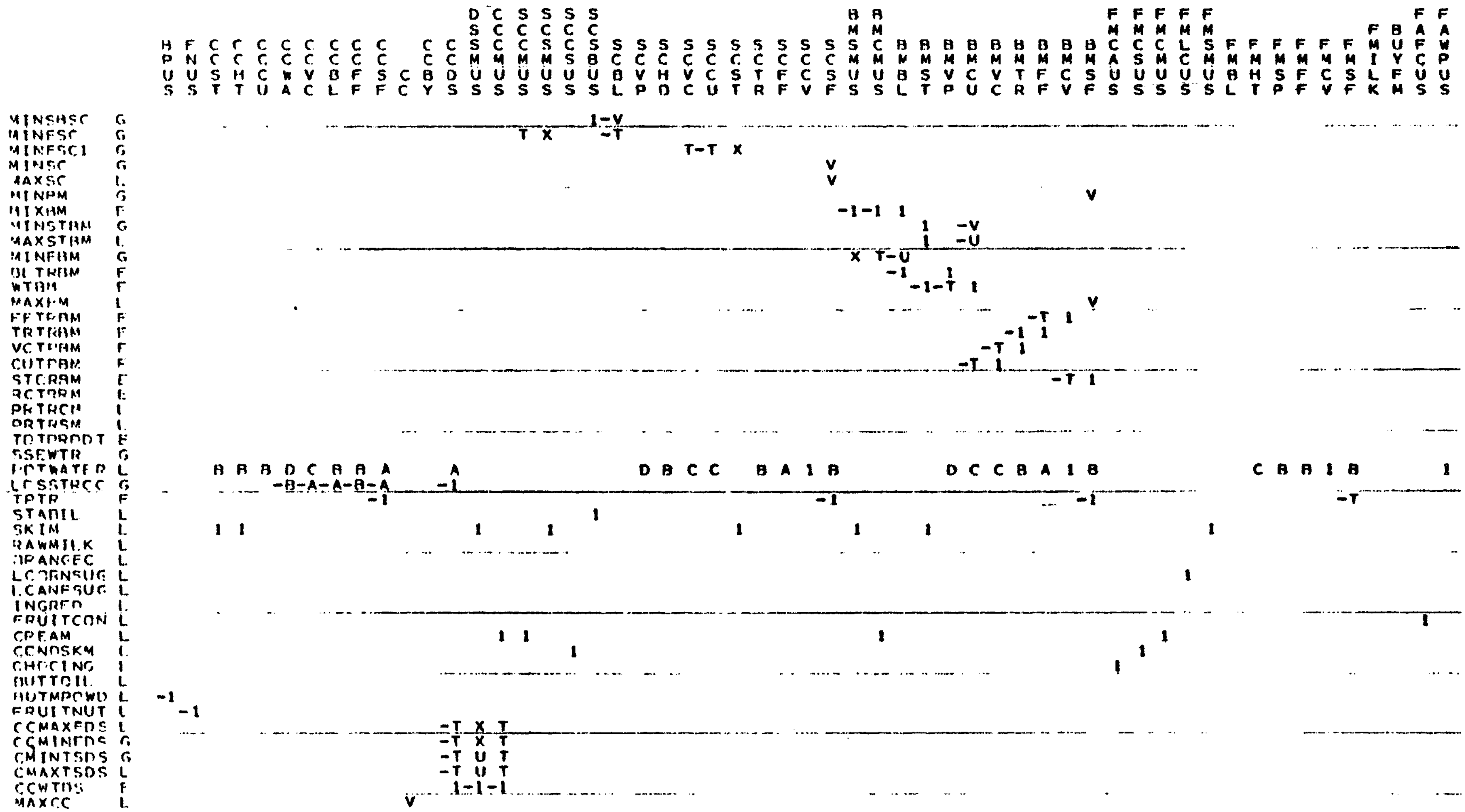


Figure 18. continued

		BPUS	FNUS	CCST	CCHT	CCCU	CCWA	CCVC	CCHL	CCFF	CCSF	CC	CCBY	CCDS	DSSMUS	CSCMUS	SCCMUS	SCSMUS	SCCSUS	SCSBUS	SCBL	SCVP	SCHO	SCVC	SCCU	SCST	SCTR	SCFF	SCCV	SCSF	HMSMUS	BMCMUS	BMBL	BMST	BMVP	BMCU	BMVC	BMTR	BMFF	BMCV	BMSF	FMCAUS	FMCSUS	FMCMUS	FMLCUS	FMSMUS	FMBL	FMHT	FMSP	FMFF	FMCV	FMSF	FMILK	BUYFM	FAFCUS	FAWPUS
MINCC	G											V																																												
CCBYTP	L										-T	1	-1																																											
STORCC	L									-T	1																																													
MAXFCC	L							X	-U						X	T																																								
MINFCC	G							X	-U						X	T																																								
WTCC	E							-T	1					-T																																										
CCMINST	G			1		-U																																																		
CCMAXST	L			1		-U																																																		
CCSET	E			-T	-T	1																																																		
YIELDCC	L					-T	1																																																	
WATRCC	I						-T	1																																																
HLTHCC	I								-T	1																																												

Figure 18. continued

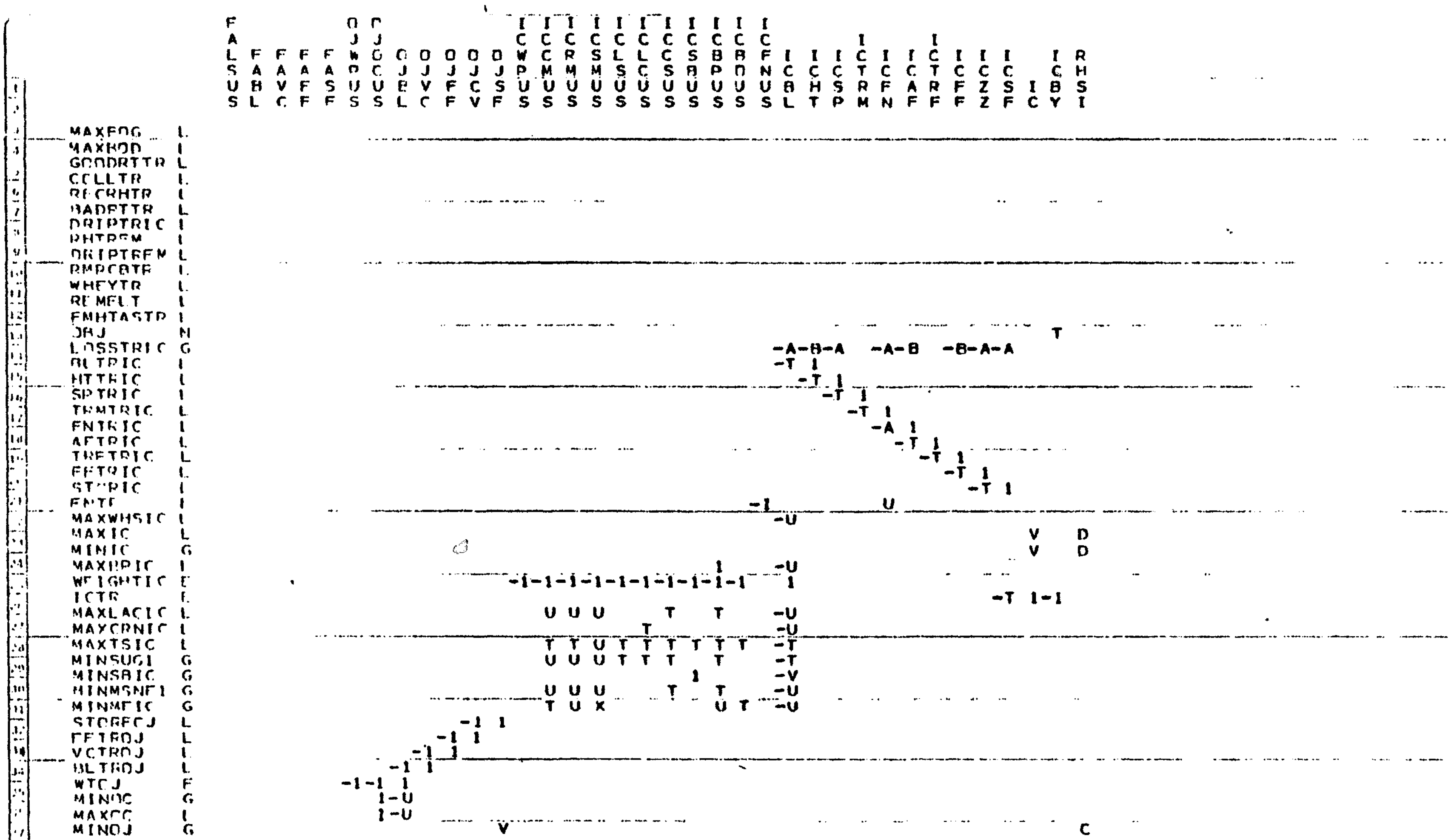


Figure 18. continued

		FALSUS	FARL	FAVC	FAFF	FASF	OJWPUS	OJOCUS	CJBL	OJVC	OJFF	OJCV	OJSF	ICWPUS	ICCMUS	ICRMUS	ICSMUS	ICLSUS	ICLCUS	ICCSUS	ICSBUS	ICBPUS	ICBOUS	ICFNUS	ICBL	ICHT	ICSP	ICTRM	ICFN	ICAF	ICTRF	ICFF	ICZZ	ICSF	IC	ICRY	RHSI
MAXOJ	I												V																								C
MAXFCFA	L		-U																																		
MAXLSFA	L	T	-T																																		
MINFCFA	G		-V																																		
MINLSFA	G	T	-U																																		
WTFA	E	-1	1																																		
BLTREFA	I		-1	1																																	
VCTREFA	L			-1	1																																
STOREFA	L				-1	1																															
MAXFA	L					V																															D
MINFA	G					V																															D
FDGTR	E																								-T	-A	-T		-T	-A		-A	-T	-T			
QCDS	F				-1						-1														-T	-A	-A		-T	-B		-B	-T	-A			
SEWERTR	F				-B						-B														-B	-C	-B		-A	-C		-B		-A			
LOSSTREM	G																																				
LOSSTRPM	G																																				
MAXSUGEM	L																																				
MINSUGEM	G																																				
MAXBEEM	L																																				
MINBEEM	G																																				
MAXMSEM	L																																				
MINMSEM	G																																				
MAXCAEM	L																																				
MINCAEM	G																																				
MIXEM	E																																				
BLTREM	L																																				
HTTREM	L																																				
SPTREM	L																																				
FETREM	L																																				
STOREM	L																																				
EMTOT	L																																				
MINEM	G																																				E
MAXEM	L																																				E
MAXSBSC	L																																				
MIXSC	F																																				
BLTRSC	L																																				
TRTRSC	L																																				
CUTRSC	L																																				
VPTRSC	L																																				
HCTRSC	L																																				
FETRSC	L																																				
STORSC	L																																				
MINSTSC	G																																				
WTSC	F																																				
MAXSNESC	L																																				
MINSNESC	G																																				

Figure 18. continued

		FALSUS	FABL	FAVC	FAFF	FASF	OJWPUS	OJOCUS	OJBL	OJVC	OJFF	OJCV	OJSF	ICWPUS	ICCMUS	ICRMUS	ICSMUS	ICLSUS	ICLCUS	ICCSUS	ICSDUS	ICBPUS	ICBOUS	ICFNUS	ICBL	ICHT	ICSP	ICTRM	ICFN	ICAF	ICTRF	ICFF	ICZZ	ICSF	IC	ICBY	RHSI
MINSBSC	G																																				
MINFSC	G																																				
MINFSC1	G																																				
MINSC	G																																				C
MAXSC	L																																				C
MINHM	G																																				D
MIXHM	E																																				
MINSTBM	G																																				
MAXSTBM	L																																				
MINFBM	G																																				
BLTRBM	E																																				
WTBM	E																																				
MAXBM	L																																				D
EFTRBM	E																																				
TRTRBM	E																																				
VCTRBM	E																																				
CUTRBM	E																																				
STORBM	E																																				
RCTRBM	E																																				
PRTRCM	L																																				
PRTRSM	L																																				
TOTPRODT	E																																				
SSEWTR	G																																				
PCTWATER	L				B		1				B			1											B	C	B		A	C		B		A			
LOSSTRCC	G																																				
IPTR	E					-1							-1																					-1			
STABIL	L																				1																
SKIM	L																1																				
RAWMILK	L															1																					
ORANGEC	L							1																													
LCORNSUG	L																		1																		
LCANESUG	L	1																1																			
INGRED	L																																				
FRUITCON	L																																				
CREAM	L														1																						
CONDSKM	L																			1																	
CHOCING	L																																				
BUTTOIL	L																						1														
BUTMPOWD	L																					1															
FRUITNUT	L																							1													
CCMAXFDS	L																																				
CCMINFDS	G																																				
CMINTSDS	G																																				
CMAXTSDS	L																																				
CCWTDS	E																																				
MAXCC	L																																				D

Figure 18. continued

		FALSUS	FABL	FAVC	FAFF	FASF	OJWPUS	OJOCUS	OJBL	OJVC	OJFF	OJCV	OJSF	ICWPUS	ICCMUS	ICRMUS	ICSMUS	ICLSUS	ICLCUS	ICCSUS	ICSBUS	ICBPUS	ICBDUS	ICFNUS	ICBL	ICHT	ICSP	ICTRM	ICFN	ICAF	ICTRF	ICFF	ICZZ	ICSF	IC	ICBY	RHSI
MINCC	G																																				D
CCHYTR	L																																				
STORCC	L																																				
MAXFCC	L																																				
MINFCC	G																																				
WTCC	E																																				
CCMINST	G																																				
CCMAXST	L																																				
CCSET	E																																				
YIELDCC	L																																				
WATRCC	L																																				
HLTRCC	L																																				

Figure 18. continued

EXECUTOR. MPS/360 V2-M11

SUMMARY OF MATRIX

SYMBOL	RANGE			COUNT (INCL.RHS)
Z	LESS THAN		.000001	
Y	.000001	THRU	.000009	2
X	.000010		.000099	15
W	.000100		.000999	18
V	.001000		.009999	40
U	.010000		.099999	89
T	.100000		.999999	171
1	1.000000		1.000000	223
A	1.000001		10.000000	75
B	10.000001		100.000000	95
C	100.000001		1,000.000000	34
D	1,000.000001		10,000.000000	24
E	10,000.000001		100,000.000000	2
F	100,000.000001		1,000,000.000000	
G	GREATER THAN		1,000,000.000000	

Figure 18. continued

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